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Arthur D. Little, Inc, Cambridge, Mass.

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16. ABSTRACT

This study assesses the likelihood of new process technology and new practices being introduced by energy intensive industries and explores the environmental impacts of such changes.

Volume 2

Specifically, Vol. II, prepared early in the study, presents and describes the overview of the industries considered and presents the methodology used to select industries. Vol. III-XV deal with the following 13 industries: iron and steel, petroleum refining, pulp and paper, olefins, ammonia, aluminum, copper, textiles, cement, glass, chlor-alkali, phosphorus and phosphoric acid, and fertilizers in terms of relative economics and environmental/energy consequences. Vol. I presents the overall summation and identification of research needs and areas of highest overall priority.

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Vol. II. Industry Priority Report

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EPA-600/7-76-034b
December 1976

ENVIRONMENTAL CONSIDERATIONS OF SELECTED ENERGY CONSERVING MANUFACTURING PROCESS OPTIONS

Volume II

INDUSTRY PRIORITY REPORT

EPA Contract No. 68-03-2198

Project Officer

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This study, consisting of 15 reports, identifies promising industrial processes and practices in 13 energy-intensive industries which, if implemented over the coming 10 to 15 years, could result in more effective utilization of energy resources. The study was carried out to assess the potential environmental/energy impacts of such changes and the adequacy of existing control technology in order to identify potential conflicts with environmental regulations and to alert the Agency to areas where its activities and policies could influence the future choice of alternatives. The results will be used by the EPA's Office of Research and Development to define those areas where existing pollution control technology suffices, where current and anticipated programs adequately address the areas identified by the contractor, and where selected program reorientation seems necessary. Specific data will also be of considerable value to individual researchers as industry background and in decision-making concerning project selection and direction. The Power Technology and Conservation Branch of the Energy Systems-Environmental Control Division should be contacted for additional information on the program.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

This study assesses the likelihood of new process technology and new practices being introduced by energy intensive industries and explores the environmental impacts of such changes.

Specifically, Vol. II, prepared early in the study, presents and describes the overview of the industries considered and presents the methodology used to select industries. Vol. III-XV deal with the following 13 industries: iron and steel, petroleum refining, pulp and paper, olefins, ammonia, aluminum, copper, textiles, cement, glass, chlor-alkali, phosphorus and phosphoric acid, and fertilizers in terms of relative economics and environmental/energy consequences. Vol. I presents the overall summation and identification of research needs and areas of highest overall priority.

This report was submitted in fulfillment of EPA Contract No. 68-03-2198 by Arthur D. Little, Inc. under the sponsorship of the U. S. Environmental Protection Agency.

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Dr. Herbert S. Skovronek, Project Officer, was a valuable resource to us throughout the study. He not only supplied us with information on work presently being done in other branches of EPA and other government agencies, but served as an indefatigable guide and critic as the study progressed. His advisors within EPA, FEA, DOC, and NBS also provided us with insights and perspectives valuable for the shaping of the study.

During the course of the study we also had occasion to contact many individuals within industry and trade associations. Where appropriate we have made reference to these contacts within the various reports. Frequently, however, because of the study's emphasis on future developments with comparative assessments of new technology, information given to us was of a confidential nature or was supplied to us with the understanding that it was not to be credited. Therefore, we extend a general thanks to all those whose comments were valuable to us for their interest in and contribution to this study.

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Pulp and Paper:	Mr. Fred D. Iannazzi, Principal Investigator Mr. Donald B. Sparrow Mr. Edward Myskowski (consultant) Mr. Karl P. Fagans Mr. G. E. Wong
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Ammonia:	Mr. John L. Sherff, Principal Investigator Ms. Nancy J. Cunningham Mr. Harry W. Lambe
Aluminum:	Mr. Richard W. Hyde, Principal Investigator Ms. Anne B. Littlefield Dr. Charles L. Kusik Mr. Edward L. Pepper Mr. Edwin L. Field Mr. John W. Rafferty
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ENGLISH-METRIC (SI) CONVERSION FACTORS

To Convert From	To	Multiply By
Acre	Metre^2	4,046
Atmosphere (normal)	Pascal	101,325
Barrel (42 gal)	Metre^3	0.1589
British Thermal Unit	Joule	1,055
Centipoise	Pascal-second	0.001
Degree Fahrenheit	Degree Celsius	$t^\circ_C = (t^\circ_F - 32)/1.8$
Degree Rankine	Degree Kelvin	$t^\circ_K = t^\circ_R/1.8$
Foot	Metre	0.3048
Foot^3/minute	Metre^3/sec	0.0004719
Foot^3	Metre^3	0.02831
Foot^2	Metre^2	0.09290
Foot/sec	Metre/sec	0.3048
Foot^2/hr	Metre^2/sec	0.00002580
Gallon (U.S. liquid)	Metre^3	0.003785
Horsepower (550 ft-lbf/sec)	Watt	745.7
Horsepower (electric)	Watt	746.0
Horsepower (metric)	Watt	735.5
Inch	Metre	0.02540
Kilowatt-hour	Joule	3.60×10^6
Litre	Metre^3	1.000×10^{-3}
Micron	Metre	1.000×10^{-6}
Mil	Metre	0.00002540
Mile (U.S. statute)	Metre	1,609
Poise	Pascal-second	0.1000
Pound force (avdp)	Newton	4.448
Pound mass (avdp)	Kilogram	0.4536
Ton (assay)	Kilogram	0.02916
Ton (long)	Kilogram	1,016
Ton (metric)	Kilogram	1,000
Ton (short)	Kilogram	907.1
Tonne	Kilogram	1,000

Source: American National Standards Institute, "Standard Metric Practice Guide," March 15, 1973. (ANS72101-1973) (ASTM Designation E380-72)

I. INTRODUCTION

The initial task under EPA Contract No. 68-03-2198 (Environmental Considerations of Selected Energy-Conserving Manufacturing Process Options) was to develop a listing of a broad group of U.S. industries for screening and to recommend selected process industry sectors for in-depth study. In performing this task, we have identified the priority placement of the industries, together with the rationale for such selection and priority placement. It was understood that, in order to accomplish this task within the initial month of the study, we would have to rely extensively on our own judgment and in-house information in making these recommendations. After reviewing the recommendations made in this report, the EPA Project Officer indicated those industries which should be studied in-depth.

In two EPA-ADL meetings in Cambridge, criteria for establishing the priority listing of industries for study were agreed upon. These included:

- the significance of environmental problems in the industry;
- the potential/probability of the implementation of the process change;
- and the total energy use within the industry.

Although the energy consequences of the process changes were important considerations, it was agreed that they were only important in terms of defining the probability of a change and in identifying those industries on which our study should be focused. The major emphasis of the study was on the environmental implications of the process change.

The body of this report has been kept brief in order to focus on the findings and conclusions of the work to date. Supporting quantitative and qualitative data generated as a basis of our conclusions are found in Appendices A and B. Selected references are shown in Appendic C.

This report was submitted in partial fulfillment of contract 68-03-2198 by Arthur D. Little, Inc. under sponsorship of the U.S. Environmental Protection Agency. This report covers a period from June 9, 1975 to July 8, 1975.

II. METHODOLOGY FOR INDUSTRY SELECTION

A. BACKGROUND

The major focus of this study was on the environmental impact of certain potential manufacturing process changes. We began the study by identifying those industries in which energy consumption is a significant factor and in which the implementation of energy-conserving process changes is possible or probable. Although an illustrative selection of industries to be studied was given in the RFP, the purpose of this initial task was to place industries in a priority order and document their placement.

Four days of EPA-ADL discussions in two separate meetings sharpened our understanding of EPA's needs in connection with this study:

- Within the 15-year time span being considered, emphasis was to be placed on industries and processes with near-term potential rather than longer term potential.
- Energy conservation was defined in the broad sense to include conservation of form value of energy (e.g., conserving natural gas while using more energy units of coal), as well as feedstock changes and actual reduction of energy use per unit of product;

In addition areas to be included within the scope of this study were:

- Changes in industrial practice that result in energy conservation, such as collection and use of CO-containing gases from basic oxygen furnaces in steelmaking;
- Pollution control methods resulting in energy conservation.

Those areas not to be included within the scope of this study were:

- Energy conservation as a result of "policing or housekeeping" (e.g., shutting off standby furnaces);
- Power generation, except for unusual situations;
- Steam raising or generation by alternative fuels (e.g., use of coal for gas or oil);
- Carbon monoxide boilers; however, unique process vent streams yielding recoverable energy could be described either qualitatively or quantitatively;

- Fuel substitution in fired process heaters;
- The agricultural sector, as well as mining and milling, except where they are or become an integral part of the process;
- Production of synthetic fuels from coal (low- and high-Btu gas, synthetic crude, synthetic fuel oil, etc.); however, coal-based processes for chemicals [such as ammonia from coal, methanol from coal, (refinery) hydrogen from coal, etc.] could be identified and might be deemed appropriate for inclusion;
- All aspects of industry-related transportation.

In addition to receiving background information from the EPA, we visited the FEA to examine information it had collected that might be relevant to this study. As a consequence, two basic types of readily available information were utilized in the identification and priority ordering of industry sectors for in-depth study:

- Quantitative factors based on gross amount of energy (fossil fuel and electric) purchased by each industry sector as found in U.S. Census figures and industry sources; and
- Qualitative factors relating to the severity of air, water, and solid waste problems, probability and potential for process change, and environmental and energy consequences of such changes.

Integration of both the quantitative and qualitative factors yielded an identification and ranking of industries which we believe show high probability for energy conservation via changes in practices or processes. We subjected the final listing to an additional review so that we could incorporate specialized factors peculiar to a specific industry and not easily accommodated in our selection and ranking process.

B. DEVELOPMENT OF QUANTITATIVE DATA

Our first objective was to identify the major energy-consuming industries. The magnitude of an industry's total energy use was believed to be an important criterion in judging where the most significant energy conservation might be realized, since even a modest process change in a major energy-consuming industry could have more dramatic national consequences than a more technically significant process change in an industry whose total energy consumption is rather modest.

For several reasons, the Census of Manufactures' data were considered to be the best source of quantitative energy-use information. Data from the Census are clearly the most comprehensive available. In discussions with industry specialists, we combined certain three- and four-digit SIC code classifications into broader two-digit classifications to achieve a more comprehensive view of several industrial groups, such as food and kindred products, glass, textiles, and pulp and paper. The methodology in using these data (employed in "Energy Consumption in Manufacturing"* by The Conference Board, under National Science Foundation, and Ford Foundation funding) came the closest to meeting our needs for purposes of ranking the industries by energy use, and that has been used almost totally throughout this study.

One drawback of the Census data is that they are based only on purchased energy; data on energy generated internally from raw material utilization (as with hydrocarbon feedstocks), or heat recovery from exothermic chemical reactions, or from wastes cannot be determined from these sources. A sense of such energy factors is best obtained from industry specialists, as discussed in Section C below.

Using the Census of Manufactures for the years 1954, 1958, 1962, 1967, and 1971, we compiled data on total purchased energy (fuel and electric power) by three- and four-digit SIC Codes for the most energy-intensive industrial sectors (see Tables A-1 through A-10 in Appendix A). Since the Census data are reported in kWh, total energy purchased was then calculated on a fossil fuel basis using 3412 Btu/kWh for fossil fuel purchased and 10,500 Btu/kWh for electric power purchased, taking into account the efficiencies of typical power plants. This exercise established total energy usage on a reasonably acceptable basis, since the Census data do not reflect the efficiency of converting fossil fuel resources into electric power. We recognize that the methodology we used does not make allowances for the utilization of hydroelectric or nuclear power. However, we believe that these approaches do not materially affect our ranking, considering the purposes for which it is to be used, since hydro and nuclear energy accounted for less than 2% of U.S. energy consumption in 1968**. These data on energy use are presented in Appendix A.

Examination of the data shows that the relative positions of the industrial sectors do not vary much from year to year. Using the 1967 data as the base year for ranking (1971 energy data on all industries are not yet available), we find it interesting to note that no industry among the first 15 of the two- and four-digit SIC codes ever ranked lower than 18 in the other years. (See Table A-11.)

Table II-1 shows the ranking of the first 16 industries in descending order of 1971 purchased energy.

As shown in Appendix A, based on the year 1967, we also calculated other factors, such as -

- energy cost per dollar value added,
- energy units required per unit of dollar value added,
- energy usage per unit of production and trends in this ratio with time,

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*Ballinger Publishing Company, Cambridge, Massachusetts (1974).

**Patterns of Energy Consumption in the United States, Office of Science and Technology, Wash., D.C., Jan., 1972.

TABLE II-1

ENERGY PURCHASED IN TOP 16 INDUSTRIES, 1971

Industry	SIC No.	10^{15} Btu/yr
1. Blast Furnaces and Steel Mills	3312	1.68
2. Petroleum Refining	2911	1.67
3. Paper and Allied Products	26	1.59
4. Stone, Clay, and Glass Products	32	1.48
5. Food and Kindred Products	20	1.266
6. Industrial Organic Chemicals (n.e.c.)*	2818	1.116
7. Industrial Inorganic Chemicals (n.e.c.)*	2819	0.805
8. Primary Aluminum	3334	0.592
9. Textile Mill Products	22	0.54
10. Alkalies and Chlorine	2812	0.236
11. Plastic Materials and Resins	2821	0.201
12. Motor Vehicle Parts and Accessories	3714	0.187
13. Motor Vehicles - Passenger Cars	3712	0.156
14. Cyclic Intermediates	2815	0.161
15. Electrometallurgical Products	3313	0.136
16. Gray Iron Foundries	3321	0.132

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*Not elsewhere classified

Source: 1972 Census of Manufactures

- purchased electric energy unit cost ($/kWh) and total purchased electricity,

- unit electric energy cost and total energy cost per dollar of value added,

- purchased fuel energy unit cost and total purchased fuel, and

- purchased fuel unit costs and total energy cost per dollar of value added.

However, these calculations seemed of little value in obtaining a better quantitative understanding of energy relationships among the industries. Consequently data from Census years other than 1967 were not similarly tested except for the time trends noted above.

C. DEVELOPMENT OF QUALITATIVE DATA

Using the quantitative listing developed above, we concentrated on our second major objective which was to identify the following for each industry on the list:

- probability or potential of energy-conserving process change,

- pollution or environmental consequences of the change, and

- energy conservation consequences of the change.

To help develop a better understanding of these more qualitative factors, industry reviews, or "industry perspectives," were developed by ADL industry specialists, most of whom attended the two EPA-ADL working sessions in Cambridge which took place in the first month of the contract. Many had also participated in earlier industry reviews and analyses undertaken at the time the proposal was submitted. The thrust of the up-dated industry perspectives was to tailor them more nearly to the needs and limitations of the EPA as articulated in the two working sessions (noted earlier in this report).

With such guidelines, the "industry perspectives" were prepared (see Appendix B). Their style differs from one to another, reflecting the particular emphasis of each ADL industry specialist. These "industry perspectives" serve as the source material used in obtaining the qualitative industry rating discussed in Chapter III of this report. Each is based on an initial assessment of that industry without benefit of in-depth research or industry contact and reflects the staff member's views as of the initiation of the project.

III. RANKING OF INDUSTRIES

A. INDUSTRY SELECTION BY QUANTITATIVE FACTORS

During development of the energy consumption data base and "industry perspectives," it became apparent that selection of the industries for priority ranking would involve making certain decisions based on nonstructured considerations. Among these were:

- Changes made by the Census Bureau in the manufacturing segments included within a given SIC category between 1967 and 1971.
- Selection of the olefins from a listing of the Industrial Organic Chemicals (n.e.c.).* This decision was based on the energy content of the raw materials which serve both as fuel and as chemical building blocks for the olefins. Purchased energy consumed is small in comparison to the energy content of the feedstocks.
- Inclusion of the alumina (SIC 2819) industry with primary aluminum (SIC 3334) because of a tie between these two industry sectors.
- Besides alumina, selection of phosphorus and phosphoric acid as the only inorganic chemical sector for consideration under Industrial Inorganic Chemicals (n.e.c.) based on its energy intensity and its importance in the industrial area.
- Removal of ammonia from the Agricultural Chemical SIC classification for consideration separately because of the high-energy value of the feedstock. Retention of the remaining fertilizers under the generic heading of fertilizers (ex-ammonia).
- Inclusion of high energy-using industries, such as motor vehicles, although they are not generally considered purely process industries.

After consideration of the above, 34 industries were chosen for consideration in developing a recommended ranking. Although these industries are among the higher energy purchasers, as determined from available data, there is more than a 50-fold factor between industries at the top and bottom of the list. This means that if a 2% energy savings were achieved in the top industry, the least energy-consuming industry would have to become a zero energy user in order to achieve the same total energy saving. Consequently, it is apparent that in developing a priority ranking, one must perceive a high probability for process changes achieving large percentage energy savings if a lesser energy-using industry were to be retained in the industries selected for further study. We believe that the energy usage spread between the first and 34th industry on our list is adequate to ensure that additions to the list, based on quantitative factors, would not be effective. This quantitative ranking in units of 10^{15} Btu (quads) is shown in Table III-1.

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*Not elsewhere classified

B. INDUSTRY SELECTION BY QUALITATIVE FACTORS

Clearly there are numerous approaches to designing a methodology for considering the qualitative factors for industry selection and ranking. Our source material was basically the "industry perspectives," already discussed, which are included in Appendix B. Ideally, it would have been desirable to have quantitative information on the potential for process change and the severity of pollution/environmental problems. However, this type of information is generally not readily available and a methodology has yet to be developed for comparing the relative magnitudes of air, water, and solid-waste problems. Thus, a less than ideal methodology was used to place industries in priority order within the one month allowed for this phase of the study. As a result, we sought a methodology which would balance out the differences in style of the industry perspectives and would allow for a less structured, experience-oriented analysis. After considering many approaches with varying degrees of structure and nonstructure, we developed a technique which we believe incorporates the essentials of both approaches.

We utilized an evaluative approach, similar in many ways to the Delphi-technique, in which five senior ADL staff members skilled in the process industries and not heavily involved in the development of the "industry perspectives" were asked to rate each industry by the following three factors:

1. Probability of Process Change

   3 - High
   2 - Likely
   1 - Small
   0 - Nil

2. Pollutional Consequences of Process Change

   3 - Major Change/Impact
   2 - Moderate Change/Impact
   1 - Small Change/Impact
   0 - Nil

3. Energy Conservation Consequences of Process Changes (Broad Definition of Energy Conservation)

   3 - Major Consequences
   2 - Moderate Consequences
   1 - Small Consequences
   0 - Nil

TABLE III-1

SUMMARY OF QUANTITATIVE AND QUALITATIVE RATING FACTORS FOR MAJOR INDUSTRIES AND THEIR INTEGRATION INTO A COMBINED INDUSTRY IDENTIFICATION AND RANKING

Methodology Ranking	Industry Segment	SIC In Which Industry Found	A Combined Qualitative Rating Factor	B Quantitative Rating Factor (Quad)^{c} Year: 1971	C Methodology Ranking Factor Product (A x B)
1.	Blast furnaces and steel mills	3312	19.	1.68	31.9
2.	Paper and allied products	26	15.	1.59	23.9
3.	Industrial organic chemicals (olefins	2818	13.0	$0.98^{(d)}$	12.7
	Cyclic intermediates and crudes only)		13.	$0.63^{(e)}$	8.2
4.	Ammonia	2871	15.	0.52	7.8
5.	Cement	3241	13.	0.59	7.7
6.	Aluminum	3334	2.9	1.68	4.9
7.	Petroleum refining	2911	6.8	0.31	2.1
8.	Glass	3211, 3221, 3229	3.4	0.55	1.8
9.	Textiles	22	19.	0.08	1.5
10.	Primary copper	3331	6.	0.13	0.8
11.	Gray iron foundries	3321	12.	.06	0.72
12.	Primary zinc	3333	2.8	0.24	0.67
13.	Alkalies and chlorine	2812	5.5	$0.12^{(f)}$	0.66
14.	Industrial inorganic chemicals (phosphorus and phosphoric acid only)	2819	6.0	$0.08^{(e)}$	0.48
15.	Fertilizers (excluding ammonia)	2871	2.7	0.14	0.38
16.	Electrometallurgical products-Ferromanganese production)	3313	0.92	0.20	0.18
17.	Plastic materials and resins	2821	1.5	.097	0.15
18.	Lime	3274	0.10	1.27	0.13
19.	Food and kindred products	20	0.53	0.18	0.10
20.	Organic fibers - noncellulosic	2824	0.45	0.15	0.068
21.	Miscellaneous plastic products	3079	0.83	.079	0.066
22.	Synthetic rubber	2822	2.3	.025	.058
23.	Carbon black	2895	0.66	.086	.057
24.	Cellulosic man-made fibers	2823	0.3	0.11	.033
25.	Inner tubes and tires	3011	.		
26-34	Other large consumers of energy				
	- motor vehicle parts, and accessories	3714	(a)	0.19	(b)
	- motor vehicles	3711	(a)	0.16	(b)
	- industrial gases	2813	(a)	0.13	(b)
	- aluminum rolling and drawing	3352	(a)	0.12	(b)
	- ready mix concrete	3273	(a)	0.091	(b)
	- beet sugar	2063	(a)	0.085	(b)
	- brick and structural clay tiles	3251	(a)	0.084	(b)
	- metal stampings	3461	(a)	0.080	(b)
	- uranium enrichment	3339	(a)	0.066	(b)

(a) Less than 0.1
(b) Less than 0.02
(c) 10^{15} Btu/yr
(d) Olefins only, includes energy of feedstocks: ADL estimates
(e) Feedstock energy included: ADL estimates
(f) Phosphorus and phosphoric acid only: ADL estimates

Each staff member undertook the rating on an individual basis. All of the staff members have been involved in technological aspects of process industries during most of their professional careers either at ADL or prior to joining the staff. They represent a total of 100 man-years of experience in the process industries.

A staff member's qualitative rating of an industry was obtained by multiplying the three rating factors. If, for example, a staff member rated an industry on a given factor in a range of from 1 to 2, a value of 1.5, halfway between, was used. The qualitative ratings were designed so that a maximum of 27 was possible (the product of three factors each having a maximum rating of 3). On the other hand, if a zero were obtained in any one of the qualitative factors (indicating either no process change, no pollution consequences, or no energy consequences of process change), then the combined weighting factor was also zero. A rating of zero was considered sufficient reason to exclude an industry from the recommended list. An average industry qualitative rating was then obtained as summarized in Table III-1.

C. FINAL SELECTION METHODOLOGY RANKING FACTOR

Table III-1 shows 25 industries with their quantitative and qualitative ratings. As an index of annual gross energy purchased by an industry, the unit of 10^{15} Btu (1 quad) was used.

Clearly there are numerous ways, all potentially subject to criticism, by which the qualitative ratings could be combined with the quantitative (energy purchased) factor to yield a priority ranking of industries. For the purpose of obtaining a "methodology ranking factor," the integration of quantitative and qualitative factors was accomplished by simply multiplying the two factors together to yield the results shown in the last column of Table III-1. After reviewing the "methodology ranking factors," and before making our final recommendations, we presented the following general observations to the Project Officer:

- The energy content in the form of feedstocks will be especially reflected in a study of the olefins and ammonia industries.

- The ranking of Gray Iron Foundries reflects a change in form value, i.e., the usual introduction of electric furnaces for fossil fuel-fired furnace, which will generally demand an overall increase in energy consumption. Because similar technologies are recommended for study in the iron and steel industry, we concluded that an in-depth analysis of Gray Iron Foundries was not warranted within the scope of this study.

- Because primary zinc and primary copper production are both non-ferrous industries, we concluded that only primary copper should be studied initially because of its greater potential for change and the pollutional consequences of these changes. Furthermore, many of the sulfur dioxide pollution problems in the zinc industry will be analogous to those found in the copper industry.

- An effort was made to select industrial sectors that demonstrate a variety of environmental impacts.

Consequently, we recommended that the following 13 industrial segments be studied in-depth.

1. Blast Furnaces and Steel Mills,
2. Paper and Allied Products,
3. Olefins,
4. Ammonia,
5. Cement,
6. Alumina and Aluminum,
7. Petroleum Refining,
8. Glass,
9. Textiles,
10. Primary Copper,
11. Alkalies and Chlorine,
12. Phosphorus and Phosphoric Acid, and
13. Fertilizers,

IV. METHODOLOGY FOR PROCESS ASSESSMENT STUDIES

A. OVERALL ASSESSMENTS

Within each industry sector chosen for inclusion in this study, processes subject to change were to be identified, using largely in-house expertise supplemented by industry contacts and discussions with consultants and the EPA Project Officer. As a result of this preliminary information-gathering step process, options were to be selected for in-depth analysis focusing on those thought to have both significant energy and environmental consequences resulting from the change.

To ensure comparability between processes to be analyzed in the various industry sectors, a common methodology was to be used in making assessments on the processes to be analyzed. Important aspects of this methodology were:

- Establishing a base line technology against which the process changes could be assessed. Normally this base line technology would be currently practiced technology in a major portion of the industry required to make a given product. In choosing base line and alternative processes, a deliberate attempt was made to start with the same or similar raw materials and produce the same or similar end-products.

- Estimating investments and operating costs (both variable and fixed costs) for both base line and alternative technology.

- Determining the energy requirements and the form of the fuel used in the base line and alternative technology. This would include establishing whether oil, gas, or coal was needed as fossil fuel, for example.

- Converting the different forms of energy used to a Btu basis. To the extent possible, common conversion factors were to be used, as indicated in Table IV-1, so that total Btu's consumed in base line and alternative technology could be compared. Only "fuels" or electric power were considered in the energy-consumed comparison. Because such a large part of electric power is fossil fuel-based, we converted all electric power to a fossil fuel equivalent using 10,500 Btu/kWh. The fossil fuel equivalent could be gas, oil, or coal but within the context of a lot of energy studies, coal is the basis because of the abundant reserves of this energy source in the United States.

- Determining the character and quantity of the pollutants emitted from the base line and alternative technology. Air, water, and solid waste were included in this assessment. Toxic, hazardous, and other emissions of environmental concern were to be identified.

TABLE IV-1

FACTORS USED TO COMPUTE KILOWATT-HOUR AND BTU EQUIVALENTS OF VARIOUS ENERGY SOURCES

Kind of fuel	Unit of measure	Killowatt-hour (1) equivalent per unit of measure	Million Btu (2) per unit of measure
Coal	Short ton . .	7,677	26.2
Coke	. . do	7,618	26.0
Fuel Oil:			
Distillate . .	Barrel (42 gal)	1,707	5.83
Residual . . .	. . do	1,842	6.29
Natural gas . .	10^3 cubic feet	303.3	1.035
Electric Power (3)			10,500 Btu/kWh-electric
Back Pressure Turbine Generator with Steam in process			4,000 Btu/kWh electric (4)

(1) Thermal kWh

(2) Higher heating value (HHV)

(3) National Average FPC (1971-80)

(4) Arthur D. Little, Inc. estimates

Source: 1972 Census of Manufacturers

- Determining the cost and energy requirements for pollution control technology to meet current or anticipated standards.

- Comparing the base line and alternative technology, based on total energy consumption and total costs for both process and pollution control. Energy consumed was determined from our background experience in the process industries, by contacting industry sources, or making engineering calculations if no other industry data existed. The Census data proved of little use because it tends to aggregate processes and also because it considers only purchased energy.

Further details are given below, focusing on:

- Costing Methodology,
- Environmental Regulations, and
- Pollution Control Technology.

B. INVESTMENTS AND OPERATING COSTS

Both investments required and operating costs were to be determined. Major variable and fixed cost factors to be considered in operating costs are shown listed below. Investment and operating costs were to be based on the first half of 1975, using March 1975 figures when available; details are given below.

MAJOR COMPONENTS OF OPERATING COSTS

Variable Costs

Raw Materials
Byproduct Credits
Energy
- Purchased Fuel
- Purchased Steam
- Electric Power Purchased
- Miscellaneous

Energy Credits
Water
Labor and Supervision
Maintenance
Labor Overhead
Misc. Variable Costs/Credits
Royalty Payments (if any)

Fixed Costs

Plant Overhead
Local Taxes and Insurance
Depreciation

TOTAL PRODUCTION COSTS

Return on Investment (pretax)

1. Fixed Investments

Capital investments (all equity basis) were based on the first half of 1975 using 1975 dollars as a basis. Capital investments include physical plant costs and other fixed capital costs that are normally allocated over the life of the investment, such as spare parts, pre-startup and startup costs, and owner's expenses. Generally, land costs, infrastructure requirements outside the plant battery limits, working capital, escalation and interest charges on debt financing during construction are not included in "Fixed Investments." In a given industry, an attempt was made to use average U.S. costs for typical plants built in the location selected. Where significant differences in working capital might be expected between the base line process and the alternative process, we attempted to take this into account in the return-on-investment calculation (see operating costs) In many cases, working capital requrements have been neglected because we felt that the differences between base line and alternative technology would be small.

2. Variable Operating Costs

Variable operating costs include:

- Raw Materials: This category includes raw materials used in the process; minor raw materials would appear under miscellaneous variable costs.

- Byproduct credits are noted here, such as chemicals from a coking facility, sulfur or sulfuric acid from a copper smelter, etc. Byproduct energy credits, such as coke oven gas, are discussed below.

- Energy: Energy-related costs, such as purchased oil, gas, coal, electric power, steam and coke, are shown under this category. Benchmark energy costs are shown in Table IV-2 for March 1975. It should be recognized that both gas and electric power rates are expected to increase substantially in the future in comparison to oil. If a process generates steam and it can be sold or used in a plant, we have assumed it had a value equivalent to the cost of producing steam from a boiler. Based on the assumption stated below, the cost of generating steam under average conditions is estimated to be about \$3.25/1000 lb when fuel oil costs \$2.00/10^6 Btu, as shown in Table IV-3.

  The following is a list of the bases used for preparing this estimate:

  - 100,000 lb/hr package boiler burning low sulfur No. 6 oil producing 450 psig saturated steam (this is a reasonably sized package boiler);
  - The boiler would operate at an average of 90% capacity for 350 days/yr;
  - A boiler efficiency of 84%, based on the higher heating value of fuel oil, has been used;
  - The boiler feedwater supply is assumed to be at 212°F, so that the heat input per pound of 450-psig steam produced is about 1025 Btu/lb.
  - It is assumed that a 5% boiler blowdown is required. (This of course depends on water quality but 5% blowdown is a reasonable figure.)

  The investment for a complete boiler facility, including fuel oil storage, building and all auxiliaries, is estimated to be \$8/lb/hr steam capacity in 1975. It has been assumed that the low-sulfur fuel oil is used; consequently no stack gas scrubbing costs have been included.

- Energy Credits: Energy credits, such as coke oven gases, byproducts from cracking operations, electric furnace reduction, byproduct steam, etc., are shown here. If such energy units can be sold or are used in the plant, they are credited normally at about \$2.00/10^6 Btu which reflects the cost of fuel oil in round numbers.

- Water: Process water and cooling water are identified separately to the extent possible. Cooling water, when shown, is based on circulation rates (not make-up rates).

- Labor and supervision costs are based on wages. Fringe benefits are taken into account under labor overhead. Benchmark hourly earnings, excluding overtime, for the various industry sectors are shown in Table IV-4.

TABLE IV-2

BENCHMARK ENERGY COSTS FOR COAL, OIL, GAS AND ELECTRIC POWER IN MARCH 1975

	Fuel Prices[a] Cents per Million Btu			Estimated Power Costs[b]
State	Coal	Oil	Gas	mils/kwh
Arizona - Phoenix	69.7	195.9	61.4	20.6
California - Los Angeles	-	241.0	80.4	21.1
Florida - Tampa	97.7	188.7	71.3	21.5
Georgia - Savannah	82.4	184.2	77.3	18.8
Illinois - Chicago	70.8	154.5	84.6	19.2
Indiana - Indianapolis	58.4	204.4	101.5	16.7
Kentucky - Louisville	65.7	198.0	55.1	12.2
Louisiana - Baton Rouge	-	172.6	58.9	14.5
New Mexico - Albuquerque	21.9	209.7	56.5	16.8
New York - Buffalo	119.9	201.0	80.1	24.8
North Carolina - Greensboro	106.3	217.1	141.6	17.9
Ohio - Cincinnati	100.2	223.9	119.7	17.0
Oregon - Portland	-	184.9	105.7	5.7
Pennsylvania - Pittsburgh	92.1	214.4	-	24.6
South Carolina - Charleston	119.7	118.2	74.5	16.5
Tennessee - Memphis	83.6	214.6	-	11.9
Texas - Houston	21.0	186.9	69.8	13.6
Utah - Salt Lake City	50.3	158.6	55.1	16.5
Virginia - Norfolk	120.3	183.1	56.0	21.3
Washington - Seattle	57.2	-	-	3.9
West Virginia - Charleston	82.8	222.6	-	17.8
Wyoming - Cheyenne	27.7	-	-	12.5

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[a] Average fuel prices paid by steam-electric plants, statewide.

[b] 1974 average statewide industrial power costs multiplied by 1.17 which is the electric power price index ratio of March 1975 to 1974 average (DOC).

Source: Chemical Week, October 22, 1975, and Arthur D. Little, Inc. adjustments as noted above.

TABLE IV-3

ESTIMATED COST OF PRODUCING 450 PSIG SATURATED STEAM (100,000 lb/hr package boiler)

Physical Investment: \$800,000
Capacity: 1.92×10^6 lb/stream day, 672×10^6 lb/yr
Operating Factor: 3 shifts/day, 350 stream days/yr

	Quantity/1000 lb	\$/Unit	\$/1000 lb
Variable Costs			
No. 6 Fuel Oil	1.22×10^6 Btu	2.00	2.440
Electric Power	3 kwh	0.025	0.075
Boiler Feedwater	0.126 10^3 gal	0.75	0.095
			2.610
Operating Labor	1 man/shift	\$6.00/man-hour	0.077
Maintenance Labor & Materials	3% of investment/yr		0.036
Labor Overhead	40% of Labor		0.031
			0.144
Fixed Costs			
Plant Overhead	60% of labor & supervision		0.046
Taxes & Insurance	2% of investment/yr		0.024
			0.070
TOTAL DIRECT COST			2.824
Depreciation - 10 years			0.119
Return on Investment (pretax) 20% of Investment/yr			0.238
TOTAL COST			3.181

TABLE IV-4

BENCHMARK EARNINGS BY SIC CODE - MARCH 1975

Industry	SIC Code	Hourly Earnings*
Aluminum	3334 - primary aluminum	\$6.47
Ammonia	287 - agricultural chemicals	4.43
Chlor-alkali	2812 - alkalies and chlorine	5.53
Copper	333 - nonferrous metals	5.75
Cement	324 - cement, hydraulic	5.93
Fertilizers	287 - agricultural chemicals	4.43
Glass	321 - flat glass	5.88
	3221 - glass containers	4.93
	3229 - pressed and blown glass, nec	4.62
Iron and Steel	3312 - blast furnaces and steel mills	6.93
Olefins	2818 - industrial organic chemicals, nec	6.07
Petroleum Refining	291 - petroleum refining	6.75
Phosphorus	2819 - industrial inorganic chemicals, nec	5.54
Pulp and Paper	261 262 266 } paper and pulp mills	5.30
	263 - paperboard mills	5.37
Textiles	22 - textiles mill products	3.30

*Gross earnings of production or non-supervisory workers

Source: Bureau of Labor Statistics, U.S. Department of Labor, Employment and Earnings, Vol. 21, No. 11, May 1975.

- Maintenance labor and materials account for annual costs to maintain a facility in good operating condition.

- Labor Overhead: Includes fringe benefits (vacations, holidays, sick leave, etc.).

- Miscellaneous variable costs/credit include catalysts, minor chemical costs, analytical services, and miscellaneous supplies. Waste disposal is not considered a "service," but a distinct pollution control cost. For reference purposes, Chemical Marketing Reporter* (March 31, 1975) was used as a reference for benchmark of miscellaneous chemicals.

3. Fixed Costs

- Plant overhead would include overhead labor (service personnel) and their fringe benefits. In addition, plant overhead includes space heating, personnel expenses, travel, telephone communications, computers, medical facilities, office supplies and services, etc. These are estimated quite often as a percent of labor costs.

- Annual local taxes and insurance are estimated at 1.5% to 2% of capital investment, depending on industry and location.

- Depreciation is calculated in these studies on a straightline basis. IRS depreciation guidelines, often used in industry feasibility studies, are used here. These guidelines are:
    - Textile Mills (excluding Finishing and Dyeing) - 14 years;
    - Textile Mills (Finishing and Dyeing) - 12 years;
    - Non-ferrous Metals (Copper, Aluminum) - 14 years;
    - Iron and Steel - 18 years;
    - Petroleum Refining - 16 years;
    - Pulp and Paper - 16 years;
    - Paper Finishing and Converting - 12 years;
    - Glass and Glass Products - 14 years;
    - Cement - 20 years; and
    - Chemicals and Allied Products (including chlor-alkali, phosphoric acid, sulfuric acid, ammonia, fertilizers, olefins) - 11 years.

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*Schnell Publishing Co., 100 Church Street, N.Y., N.Y.

4. Return on Investment

In order to:

- give recognition to the time value of money, while covering financial charges and costs, and to
- allow for a reasonable return on investment,

we have shown an annual allowance for "return on investment" (pretax) amounting to 20% of the initial capital investment. The allowance is allocated to a ton of product by assuming that the facility operates at 100% capacity. Obviously, for any company making capital allocation decisions, a more definitive analysis would undoubtedly be made including examination of the risks entailed in a new project, type of industry, market and business conditions, etc., but such assessments were considered to be outside the scope of this study.

5. Miscellaneous Fixed Costs/Credits

Items not normally considered above need an explanatory remark, including, for example, depletion allowances, or royalty payments based on production for proprietary technology, or licensing costs. Paid-up royalties would normally be included under "capital investments."

C. ENVIRONMENTAL REGULATIONS

Selected State air emission regulations along with the Federal Government's stationary source performance standards and effluent limitation guidelines were surveyed to:

- establish the most probable limits of air and water emissions, and
- obtain a perspective of the types of pollution control systems to be considered.

At the State regulatory level, there are a large number of different regulations for airborne emissions. Nevertheless we found that approximately the same type of air pollution control systems would be required, regardless of what State or Federal regulations were to be met.

For water effluents we chose the EPA Best Available Technology Economically Achievable (BATEA) Guidelines (1983) as the effluent limitations that would have to be met for both currently practiced and alternative processes considered. The rationale for this choice was that any plant employing the technologies evaluated in these reports should install wastewater treatment systems capable of meeting BATEA standards, although at the time of construction the New Source Performance Standards might be applicable. Because regulations for the handling and disposal of solid waste are either non-specific or non-existent, we chose various types of controlled landfill disposal methods, where our judgment suggested potential adverse environmental impacts might occur from uncontrolled disposal.

D. POLLUTION CONTROL COSTS

Development of the pollution control costs for both the base line and new processes was to be based upon estimates of capital and operating costs for selected pollution control technologies believed to be most applicable to the various manufacturing processes. In selecting the particular pollution control technology for cost estimation, we chose that which is judged to be the best available for the particular pollution problem. This generally meant that, for water pollution control, the technology was most similar to that designated in the Development Documents for effluent limitation guidelines, while for airborne particulates, it was most often high-efficiency scrubbers or fabric filters.

Preliminary sizing of the major components of the pollution control system was to be based on estimated flow rates and compositions of air and water streams anticipated for the plant capacity chosen to establish the probable manufacturing costs for the process. The estimated installed cost of pollution control equipment was based on a new plant construction site, i.e., no provisions were made for the many site-specific factors, such as plant age, unusual layout, etc., that could affect construction costs at an existing facility. Consequently, the estimated capital investment for pollution control systems in these reports is not intended to be compared with costs of similar systems that might have been incurred by presently operating plants. On the other hand, the pollution control cost estimates were prepared on a basis consistent with the preparation of similar cost estimates for the production process and, therefore, should give a good indication of the relative significance of pollution control costs as a fraction of total production costs.

Capital investment estimates of pollution control equipment were to be based on data from cost-estimating literatures, equipment vendors, operating plants, and from our own engineering files. In certain industries, such as iron and steel, plastics and synthetics, textiles, and pulp and paper, we have accumulated extensive cost data on presently installed pollution control systems from previous work, and this data was relied on extensively. Sometimes it was found most expedient to scale capital estimates from other time periods and of different capacity to that desired for this study. Capacity-related scaling was determined by a relationship such as:

$$\frac{\text{Capital}_1}{\text{Capital}_2} = \left[\frac{\text{Capacity}_1}{\text{Capacity}_2}\right]^a$$

where the exponent "a" is typically between 0.5 and 0.7, depending upon the type of pollution control system; for example, large-volume conventional wastewater treatment systems would be near 0.5, while specialized systems, such as activated carbon adsorption, would be closer to 0.7. All capital costs were normalized to a period of approximately March 1975, using an Engineering News Record Construction Cost Index of 2126. Although other methods for normalization of capital investments, such as the Chemical

Engineering Plant Cost Index published by McGraw Hill, or the Marshall & Swift Equipment Cost Index, might be used, we have chosen the ENR Construction Cost Index because we believe it to be more representative of the manner in which the cost of pollution control systems has increased in the past.

Annualization of capital investment for pollution control was based on two factors. One is the depreciation guideline periods established by the Internal Revenue Service for the particular industry, as noted in the costing methodology section for the processes. The second factor in annualization of initial capital invested is designated as return on investment (ROI), amounting to an annual charge of 20% of investments which gives recognition to the time value of money by covering financial charges and costs and allowing for a reasonable return on investment. Although it might be argued that industry should not be permitted a return on pollution control equipment investment, the total annualization charges are not significantly different from those that would have been established, if it were assumed that money was borrowed at 10% interest for a period of 10 years and that straight-line depreciation over a 10-year period was taken for all pollution control equipment. This latter method would result in annual charges of 26.27%, while the method described above (and used here) gives annual charges (for ROI plus depreciation) of between 25% and 29.1%, depending on depreciation period.

Direct operating costs and fixed charges were developed in the following manner:

- Fuel, electricity, and steam costs are based on established quantities and the rates used were established for the industrial sectors.
- Operating labor and assigned overheads are the same as for the industrial sector of interest.
- Annual maintenance materials and labor were taken as a percentage of capital investment and were based on our estimate of the probable severity of operating conditions for the system.
- Costs for chemicals and other supplies needed to operate the pollution control system were typical of those reported in the March 31, 1975 issue of the Chemical Marketing Reporter published by Schnell Publishing Company.
- Annual taxes and insurance were taken as 2% of capital investment.
- Solid residue disposal was taken as a direct operating cost, typically $5/ton for wastes that might go into average conventional sanitary landfill. If special requirements for land disposal were required, the costs for preparation of an area to receive the annual quantity of residuals was taken as an expense item.

The estimated annual costs for pollution control, along with the estimated energy consumed by the pollution control equipment, were established on the same unit production bases as used in preparing the production estimates.

The above described method for estimating costs for pollution control is consistent with procedures used throughout other studies developing estimates of the economic impact of pollution control on an industry (e.g., EPA Development Documents for Proposed Effluent Limitations guidelines; Steel and the Environment, A Cost Analysis, for the American Iron and Steel Institute; and Estimated Potential Costs to Meet Regulations of the 1972 Clean Water Act, a report to the National Council of the Paper Industry for Air and Stream Improvement). However, it must be recognized that the estimated pollution control costs of new processes were based many times on either limited information on the probable magnitude of the polluted streams to be treated, or upon "best engineering" estimates prepared from conceptual flowsheets. Furthermore, the technologies chosen may not be adequate to meet future, as yet undefined, regulations. Although these estimates were prepared in a manner which can readily be revised to other bases in time or to plants of different capacities, it is necessary that appropriate recognition be given to scaling factors. For example, while capacity relating to scaling of capital investment usually follows a power function relationship (e.g., 0.6), energy, fuel, and chemicals are usually directly related to capacity, while labor is related to capacity by a power function relationship that is usually much lower than for capital investment, e.g., 0.3 to 0.6. Consequently, it cannot be too strongly stressed that scaling must be done in a judicious manner, taking into consideration the appropriate variations of individual factors.

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APPENDIX A

ENERGY DATA

TABLE A-1

RANKING BY TOTAL FUEL AND ELECTRIC ENERGY PURCHASED (3-DIGIT SIC GROUPING) 1954

SIC CODE	INDUSTRY GROUP	RANK	Purchased Fuel (10^9 kWh Equiv.*)	Purchased Electric Energy (10^9 kWh)	Total Purchased Energy (10^9 kWh Equiv.)	Purchased Fuel (10^{15} Btu)	Purchased Electric Energy (10^{15} Btu)	Total Purchased Energy (10^{15} Btu)	Total Energy Cost ($\$10^6$)	Value Added by Manufacture ($\$10^6$)	Energy Cost/ Value Added (¢/$)	Energy/ Value Added (10^6 Btu/$)
331	Blast Furnaces and Steel Products	1	1495.2	17.667	1513.89	5.1061	.1855	5.2916	1370.7	4755.2	28.82	1.1128
261	Pulp, paper and Board	2	158.46	9.352	167.81	.541	.09819	.6392	271.9	2289.3	11.87	.2792
282	Organic Chemicals	3	147.51	6.144	153.65	.5037	.0645	.5682	173.24	3214.4	5.39	.1768
281	Inorganic Chemicals	4	58.41	34.312	92.72	.1994	.3603	.5597	314.9	1386.5	22.71	.4037
333	Primary Nonferrous Metals	5	63.136	20.949	84.134	.2156	.2199	.4355	112.9	614.15	18.39	.7091
322	Glass & glassware Pressed or Blown	6	32.99	14.335	33.47	.1126	.1505	.2631	55.14	674.38	1.648	.3901
202	Dairy Products	7	52.6	2.433	55.1	.1796	.0255	.2051	103.8	2256.7	4.60	.0909
371	Motor Vehicles and Equipment	8	37.68	5.785	43.47	.1286	.06074	.1893	125.9	6406.6	1.96	.0296
325	Structural Clay Products	9	49.1	.683	49.8	.1676	.007171	.1748	61.84	425.3	14.53	.4109
332	Iron and Steel Foundries	10	34.328	2.518	36.846	.1172	.02643	.1436	96.73	1339.2	7.22	.10726
209	Miscellaneous Food and Kindred Products	11	31.96	29.96	2.004	.1023	.02104	.1233	53.92	1632.6	3.303	.0755
201	Meat Products	12	29.34	2.082	31.4	.1001	.02186	.12196	63.6	1930.9	3.29	.0632
339	Primary Metal Industry n.e.c.	13	23.55	2.070	25.62	.0804	.02173	.1021	61.55	1184.7	5.196	.0862
208	Beverages	14	24.41	1.147	25.56	.0833	.01204	.0953	47.12	2237.4	2.106	.0426
372	Aircrafts & Parts	15	13.68	4.307	17.99	.04671	.04522	.09193	66.50	628.76	1.058	.0146
289	Miscellaneous Chemical Products	16	17.35	2.154	19.50	.0592	.02262	.08187	35.76	1128.5	3.169	.0725
206	Sugar	17	22.6	57.0	22.6	.0771	.000598	.0777	23.31	250.7	9.299	.3099
335	Nonferrous Rolling and Drawing	18	12.49	2.462	14.95	.04265	.02585	.0685	43.92	860.2	5.107	.0796
329	Miscellanaous Non-Metallic Minerals Products, n.e.c.	19	14.74	1.121	15.85	.05033	.01177	.0621	29.95	662.6	4.519	.0937
203	Canned, Cured & Frozen	20	15.2	844	16.0	.0519	.00886	.06076	34.20	1301.1	2.629	.0467
205	Bakery Products	21	14.016	1.137	15.153	.04786	.011938	.059805	46.336	1977.18	2.3435	.03026
242	Lumber & Basic Products	22	10.53	2.056	12.59	.0359	.021588	.0575	57.23	1595.3	3.587	.0361
344	Structual Metal Products	23	8.6	1.357	9.96	.02936	.01425	.0436	35.66	2203.6	1.618	.0198
346	Metal Stamping and Coating	24	8.9	1.235	10.2	.03039	.01296	.04335	34.8	1245.0	2.800	.0348
366	Communication Equipment	25	6.8	1.556	8.4	.02322	.016338	.0396	31.106	321.4	.968	.0123
356	General Industrial Machinery	26	7.480	1.043	8.523	.02554	.01095	.03649	28.215	1859.05	1.5177	.01963
354	Metalworking Machinery	27	6.699	1.122	7.821	.02287	.01178	.03465	28.57	2390.1	1.2156	.01474
221	Woolen and Worsted Manufactured	28	7.71	.622	8.33	.02632	.00653	.03285	20.26	452.9	4.47	.0725

*Equiv. = Equivalent

TABLE A-2

RANKING BY TOTAL FUEL AND ELECTRIC ENERGY PURCHASED (3-DIGIT SIC GROUPING) 1958

SIC CODE	INDUSTRY GROUP	RANK	Purchased Fuel (10^9 kWh Equiv.*)	Purchased Electric Energy (10^9 kWh)	Total Purchased Energy (10^9 kWh Equiv.)	Purchased Fuel (10^{15} Btu)	Purchased Electric Energy (10^{15} Btu)	Total Purchased Energy (10^{15} Btu)	Total Energy Cost ($\$10^6$)	Value Added by Manufacture ($\$10^6$)	Energy Cost/ Value Added (c/$)	Energy/ Value Added (10^6 Btu/$)
281	Industrial Chemicals	1	261.0	79.4	340.4	0.891	0.8339	1.725	598.3	4259.8	14.04	0.4050
331	Blast Furnace and Steel Products	2	333.3	22.2	355.5	1.138	0.2326	1.371	732.8	6862.9	10.68	0.1997
291	Petroleum Refining	3	250.9	9.1	260.0	0.857	0.0957	0.952	240.0	2119.4	11.32	0.4494
324	Cement Hydraulic	4	110.1	5.0	115.1	0.376	0.0527	0.429	161.5	724.8	22.28	0.5914
262	Papermills, except Building Paper	5	104.9	6.2	111.1	0.358	0.0649	0.423	165.9	1541.8	10.76	0.2744
333	Primary Nonferrous Metals	6	62.4	19.1	81.5	0.213	0.2009	0.416	132.7	700.4	18.95	0.5911
263	Paperboard Mills	7	78.4	2.5	80.9	0.268	0.0258	0.294	109.2	840.1	13.0	0.3495
282	Plastic Materials and Synthetics	8	61.7	2.8	64.5	0.211	0.0293	0.240	86.3	1899.8	4.54	0.1264
371	Motor Vehicles and Equipment	9	41.9	7.0	48.9	0.143	0.0737	0.217	145.2	6750.7	2.15	0.0321
202	Dairy Products	10	36.8	3.1	39.9	0.126	0.0327	0.158	107.6	2864.8	3.76	0.0553
325	Structural Clay Products	11	38.3	0.85	39.2	0.131	0.0089	0.140	68.7	490.5	14.0	0.2849
322	Glass and Glassware Pressed and Blown	12	35.0	1.9	36.9	0.119	0.0196	0.139	67.1	844.8	7.94	0.1647
335	Nonferrous Rolling and Drawing	13	23.2	4.2	27.4	0.079	0.0445	0.124	78.8	1726.0	4.57	0.0717
201	Meat Products	14	26.8	2.4	29.2	0.092	0.0255	0.117	68.5	2499.2	2.74	0.0468
327	Concrete Gypsum and Plaster Products	15	29.6	1.5	31.0	0.101	0.0153	0.116	81.1	1548.4	5.23	0.0752
332	Iron and Steel Foundries	16	25.0	2.6	27.7	0.085	0.0278	0.113	100.1	1322.2	7.57	0.0856
204	Grain Mill Products	17	22.4	2.4	24.8	0.0765	0.0257	0.102	55.3	1855.7	2.98	0.0551
372	Aircrafts and Parts	18	13.4	5.0	18.4	0.046	0.0527	0.098	76.0	6924.3	1.01	0.0142
221	Weaving Mill, cotton	19	11.9	5.2	17.1	0.041	0.0546	0.095	55.8	1078.6	5.18	0.0883
206	Sugar	20	24.8	0.1	24.9	0.085	0.0009	0.086	29.6	337.1	8.77	0.2540
208	Beverages	21	20.1	1.5	21.6	0.069	0.0155	0.084	53.9	2835.7	1.90	0.0297
209	Miscellaneous Food and Kindred products	22	14.2	3.0	17.3	0.0485	0.0320	0.080	74.1	1859.1	3.98	0.0433
203	Canned, Cured and Frozen Foods	23	18.5	1.3	19.8	0.063	0.0133	0.0765	48.15	1895.7	2.54	0.0403
329	Miscellaneous Nonmetallic Mineral Products	24	16.7	1.7	18.4	0.057	0.0182	0.075	49.6	1001.7	4.95	0.0751
226	Textile finishing, except wool	25	17.5	0.8	18.4	0.0598	0.0086	0.068	35.9	455.9	7.88	0.1499
222	Weaving Mills, synthetics	26	3.5	5.2	8.7	0.012	0.0546	0.067	18.0	468.6	3.84	0.1421
205	Bakery Products	27	14.0	1.2	15.3	0.048	0.0132	0.061	61.4	2634.3	2.33	0.0232
339	Miscellaneous Primary Metal Products	28	14.1	0.8	14.9	0.046	0.0089	0.057	37.6	441.8	8.51	0.1291
344	Fabricated Structural Metal Products	29	10.4	1.9	12.3	0.0355	0.0197	0.055	51.8	2962.9	1.75	0.0186
266	Building Paper & Board Mills	30	12.3	1.2	13.5	0.042	0.0127	0.055	26.5	2215.1	12.31	0.2543
242	Sawmills and Planing Mills	31	9.9	1.9	11.8	0.036	0.0198	0.054	64.7	1341.1	4.83	0.0400
261	Pulp Mills	32	12.4	0.6	13.0	0.042	0.0062	0.049	25.3	196.0	12.89	0.2479
321	Flat Glass	33	11.8	0.6	12.4	0.040	0.0064	0.047	19.0	263.2	7.21	0.1775
289	Misc. Chemical Products	34	9.6	0.9	10.5	0.033	0.0090	0.042	30.3	804.5	3.76	0.0519

353	**Construction and like Equipment**	35	7.2	1.5	8.7	0.025	0.0154	0.040	34.3	2054.8	1.67	0.0195
283	**Drugs**	36	8.8	0.9	9.7	0.030	0.098	0.040	22.9	2096.3	1.09	0.1903
264	**Paper & Paperboard Products**	37	8.3	1.0	9.3	0.028	0.0107	0.039	28.1	1412.9	1.99	0.0276
265	**Paperboard Containers and boxes**	38	7.8	0.97	8.8	0.027	0.0102	0.037	27.0	1501.6	1.80	0.0245
356	**General Industry Machinery**	39	5.6	1.3	6.9	0.019	0.0140	0.033	35.3	1935.2	1.82	0.0171
362	**Electric Industrial Apparatus**	40	N/A	2.0	N/A	N/A	0.0205	N/A	29.8	1447.8	2.06	N/A
284	Cleaning and Toilet Goods	41	8.0	0.4	8.4	0.027	0.0047	0.032	19.2	1903.1	1.01	0.0168
346	Metal Stamping	42	6.3	0.9	7.2	0.022	0.0099	0.031	24.7	1049.3	2.36	0.0300
307	Misc. Plastic Products	43	4.6	1.3	5.9	0.016	0.0140	0.030	29.1	929.0	3.13	0.0320
295	Paving & Roofing	44	7.3	0.3	7.6	0.025	0.0032	0.028	18.2	269.0	6.75	0.1045
336	Nonferrous Foundries	45	5.4	0.6	6.0	0.018	0.0064	0.025	21.0	470.7	4.47	0.0528
223	Weaving & Finishing Mills, wool	46	5.1	0.6	5.7	0.017	0.0062	0.024	16.0	336.6	4.76	0.0703
354	Metalworking machinery	47	2.9	1.2	4.1	0.010	0.0129	0.023	34.8	2058.5	1.69	0.0111
225	Knitting Mills	48	4.1	0.8	4.9	0.014	0.0086	0.023	21.6	1101.4	1.96	0.0205
367	Electronic Components	49	3.0	1.2	4.2	0.010	0.0122	0.022	22.2	1433.9	1.55	0.0157
366	Communication Equipment	50	4.2	0.7	4.9	0.014	0.0077	0.022	16.3	2038.4	0.80	0.0108
275	Commercial Printing	51	2.2	1.2	3.4	0.008	0.0125	0.020	31.1	2344.5	1.33	0.0085
243	Millwork & related Products	52	1.6	1.0	2.6	0.006	0.0103	0.016	20.8	925.0	2.25	0.0171
241	Logging Camp & Logging Contract	53	4.3	0.1	4.4	0.015	0.0006	0.015	18.7	387.4	4.84	0.0395
249	Miscellaneous wool Product	54	2.8	0.3	3.1	0.010	0.0032	0.013	10.9	339.5	3.20	0.0376
347	Metal Services, n.e.c.	55	1.7	0.7	2.4	0.006	0.0069	0.013	17.7	362.2	4.88	0.0351
326	Pottery & Related Products	56	1.9	0.3	2.2	0.006	0.0079	0.009	12.9	283.9	4.55	0.0329
287	Agricultural Chemicals	57	N/A	0.6	N/A	N/A	0.0067	N/A	14.9	416.8	3.58	N/A
328	Cut Stone, Stone Products	58	0.7	0.1	0.8	0.0024	0.0013	0.004	3.9	129.0	3.03	0.0285
286	Gum and Wood Products	59	.6	0.1	0.7	0.002	0.001	0.003	4.6	85.3	5.38	0.0365
279	Printing Trade Services	60	0.2	0.2	0.4	0.0007	0.0016	0.002	4.2	390.0	1.09	0.0059

*Equiv. = Equivalent

TABLE A-3

RANKING BY TOTAL FUEL AND ELECTRIC ENERGY PURCHASED (3-DIGIT SIC GROUPING) 1962

SIC CODE	INDUSTRY GROUP	RANK	Purchased Fuel (10^9 kWh Equiv.)	Purchased Electric Energy (10^9 kWh)	Total Purchased Energy (10^9 kWh Equiv.)	Purchased Fuel (10^{15} Btu)	Purchased Electric Energy (10^{15} Btu)	Total Purchased Energy (10^{15} Btu)	Total Energy Cost ($\$10^6$)	Value Added by Manufacture ($\$10^6$)	Energy Cost/ Value Added (c/$)	Energy/ Value Added (10^6 Btu/$)
281	Basic Chemicals	1	342.1	81.3	423.4	1.168	0.853	2.022	715.5	6,171.2	11.6	0.328
331	Steel Rolling & finishing	2	342.3	29.3	371.7	1.169	0.3031	1.472	889.3	8,617.3	10.32	0.171
291	Petroleum Refining	3	311.3	12.1	323.4	1.063	0.1275	1.191	336.9	3,137.6	10.76	0.379
333	Primary Nonferrous Metal	4	82.4	30.5	112.9	0.281	0.320	0.601	177.3	1,012.6	17.51	0.594
324	Cement, Hydraulic	5	121.2	5.9	127.1	0.414	0.0621	0.476	172.0	785.7	21.89	0.606
262	Paper Mills, Except Building Paper	6	113.1	8.3	121.4	0.386	0.0871	0.473	197.5	1,857.2	10.63	0.255
263	Paperboard Mills	7	85.3	3.2	88.5	0.291	0.0335	0.325	122.1	1,186.2	10.29	0.274
282	Plastic Materials & Synthetics	8	69.0	4.4	73.4	0.235	0.0461	0.282	107.9	2,865.4	3.77	0.0983
371	Motor Vehicles & Equipment	9	47.0	10.2	57.2	0.161	0.1074	0.268	187.6	12,780.6	1.47	0.0209
325	Structural Clay Products	10	45.8	1.0	46.8	0.157	0.0108	0.167	77.9	553.8	14.07	0.302
322	Pressed & Blown Glass	11	40.6	2.5	43.1	0.139	0.0267	0.165	86.2	1,101.8	7.82	0.150
202	Dairy Products	12	31.2	3.7	34.9	0.107	0.0386	0.145 (2)	123.4	3,184.9	3.87	0.0456
335	Nonferrous Rolling & Drawing	13	25.3	5.6	30.9	0.087	0.0587	0.145 (1)	96.4	2,127.7	4.53	0.0682
332	Iron & Steel Foundries	14	28.4	3.6	32.0	0.097	0.0377	0.135	130.6	1,959.9	6.66	0.0687
204	Grain Mill Products	15	26.8	3.0	29.8	0.092	0.0312	0.123	70.5	2,271.1	3.1	0.054
327	Concrete and Plaster Products	16	28.2	2.1	30.2	0.096	0.0216	0.118	106.3	2,122.3	5.01	0.0555
209	Food & Miscellaneous Kindred Products	17	33.5	3.5	37.0	0.114	0.0371	0.114	91.9	2,405.7	3.82	0.0475
201	Meat Products	18	24.5	2.9	27.3	0.084	0.0302	0.1138	77.1	2,882.6	2.67	0.0395
372	Aircraft & Parts	19	14.4	5.8	20.2	0.049	0.0605	0.110	85.1	7,867.3	1.08	0.014
329	Nonmetallic Minerals, nec.	20	23.6	2.4	25.9	0.081	0.0247	0.105	62.9	1,337.6	4.70	0.0787
208	Beverages	21	24.7	1.7	26.4	0.084	0.018	0.102	60.9	3,724.8	1.63	0.0274
206	Sugar	22	29.1	0.2	29.3	0.099	0.0023	0.1016	36.2	590.8	6.13	0.172
203	Canned & Frozen Foods	23	23.0	1.9	24.9	0.079	0.0196	0.0982	63.7	2,778.8	2.29	0.0125
221	Weaving Mills, Cotton	24	10.6	5.9	16.5	0.036	0.062	0.0981	57.7	1,256.8	4.59	0.0781
226	Textile Finishing, Except Wool	25	18.8	0.9	19.6	0.064	0.0919	0.0835	37.3	582.3	6.41	0.1434
301	Tires & Inner Tubes	26	15.8	2.2	18.0	0.054	0.0227	0.0767	34.6	1,321.7	2.62	0.058
261	Pulp Mills	27	18.9	1.1	20.1	0.065	0.0119	0.07667	30.0	295.8	10.1	0.259
289	Miscellaneous Chemical Products	28	17.2	1.0	18.2	0.059	0.0104	0.0693	32.9	1,035.5	3.18	0.0669
242	Sawmills & Planing Mills	29	12.6	2.3	14.9	0.043	0.0242	0.0673	67.6	1,572.5	4.3	0.043
266	Building Paper & Board Mills	30	14.9	1.4	16.3	0.051	0.0149	0.0659	30.7	153.1	20.05	0.4303
205	Bakery Products	31	14.2	1.5	15.7	0.049	0.0158	0.0643	54.9	3,030.8	1.81	0.0212
344	Structural Metal Products	32	12.1	2.2	14.3	0.041	0.0227	0.0641	60.5	3,219.8	1.88	0.0199
264	Misc. Converted Paper Products	33	13.2	1.6	14.8	0.045	0.0167	0.0618	40.3	1,962.4	2.06	0.0315
339	Primary Metal Industries	34	13.4	1.1	14.5	0.046	0.012	0.0577	46.1	658.3	7.0	0.0876

353	Construction & Related Machinery	35	10.6	2.0	12.6	0.036	0.0213	0.0573	42.2	2,732.3	1.55	0.021
321	Flat Glass	36	12.8	0.8	13.6	0.044	0.0087	0.0523	23.6	364.5	6.47	0.144
356	General Industrial Machinery	37	9.1	1.9	11.0	0.0312	0.0195	0.0507	42.4	2,812.7	1.51	0.018
283	Drugs	38	10.0	1.3	11.3	0.0342	0.0136	0.0478	28.4	2,807.3	1.01	0.017
265	Prepared Containers & Boxes	39	9.6	1.4	11.0	0.0327	0.015	0.0477	38.1	1,941.0	1.36	0.0246
354	Metalworking Machinery	40	8.5	1.7	10.2	0.029	0.0179	0.0469	44.7	3,037.7	1.47	0.021
362	Electrical Industrial Apparatus	41	6.3	2.3	8.6	0.0213	0.0244	0.0457	34.5	1,889.2	1.83	0.0262
349	Misc. Fabricated Metal Products	42	8.0	1.4	9.3	0.0271	0.0142	0.0413	36.9	1,725.8	2.14	0.0239
366	Communication Equipment	43	5.5	2.0	7.5	0.0186	0.0207	0.0393	32.5	5,341.5	0.61	0.0074
367	Electronic Components	44	4.5	2.2	6.7	0.0153	0.0228	0.0381	36.6	2,508.1	1.46	0.0152
295	Paving & Roofing Materials	45	9.8	0.4	10.2	0.0333	0.0045	0.0378	24.4	355.6	6.86	0.1063
287	Agricultural Chemicals	46	7.2	1.2	8.4	0.0246	0.0124	0.0370	25.4	628.3	4.03	0.0589
284	Soap, Cleaners & Toilet Goods	47	8.8	0.6	9.4	0.0299	0.0065	0.0364	22.6	2,866.4	0.79	0.0127
225	Knitting Mills	48	7.4	1.1	8.4	0.0251	0.0112	0.0363	28.3	1,396.0	2.03	0.026
336	Nonferrous Foundries	49	7.2	0.9	8.2	0.0247	0.0096	0.0343	28.3	656.5	4.31	0.0523
222	Weaving Mills, Synthetics	50	4.4	1.8	6.2	0.015	0.0185	0.0335	20.8	661.5	3.14	0.0506
307	Plastic Products, nec	51	6.9	2.4	9.3	0.0237	0.0025	0.0332	48.3	1,660.1	2.91	0.0201
243	Millwork, Plywood, Related Products	52	4.8	1.3	6.2	0.0165	0.014	0.0305	27.3	1,239.8	2.2	0.0266
347	Metal Services	53	6.0	0.8	6.8	0.0204	0.0088	0.0292	27.8	554.7	5.01	0.0526
241	Logging Camps & Contractors	54	7.3	0.2	7.5	0.0251	0.002	0.0271	30.0	520.5	5.76	0.052
223	Weaving, Finishing Mills, Wool	55	5.4	0.7	6.1	0.0184	0.0072	0.0256	15.6	386.6	4.04	0.0662
346	Metal Stampings	56	6.8	1.1	7.9	0.0233	0.0041	0.0247	29.3	1,369.0	2.14	0.0178
326	Pottery & Related Products	57	5.5	0.3	5.8	0.0189	0.0332	0.0220	13.8	337.2	4.09	0.0652
275	Commercial Printing	58	5.1	1.6	6.7	0.0174	0.0017	0.0190	39.5	2,961.1	1.33	0.0064
249	Misc. Wood Products	59	3.4	0.4	3.9	0.0117	0.0046	0.0163	16.2	513.6	3.15	0.0317
286	Gum & Wood Chemicals	60	2.3	0.1	2.4	0.0078	0.0013	0.0091	5.5	100.3	5.48	0.0897
328	Cut Stone & Stone Products	61	0.6	0.2	0.8	0.0021	0.0020	0.0041	5.0	131.5	3.8	0.0311
279	Printing Trade Services	62	0.09	0.2	0.3	0.0003	0.0019	0.0023	5.0	434.4	1.15	0.00504

*Equiv. = Equivalent

TABLE A-4

RANKING BY TOTAL FUEL AND ELECTRIC ENERGY PURCHASED (3-DIGIT SIC GROUPING) 1967

SIC CODE	INDUSTRY GROUP	RANK	Purchased Fuel (10^9 kWh Equiv.)	Purchased Electric Energy (10^9 kWh)	Total Purchased Energy (10^9 kWh Equiv.)	Purchased Fuel (10^{15} Btu)	Purchased Electric Energy (10^{15} Btu)	Total Purchased Energy (10^{15} Btu)	Total Energy Cost ($\$10^6$)	Value Added by Manufacture ($\$10^6$)	Energy Cost/ Value Added (c/$)	Energy/ Value Added (10^6 Btu/$)
281	Industrial Chemicals	1	452.54	78.62	531.17	1.545	0.826	2.371	838.7	7736.6	10.841	0.307
331	Blast Furnaces & Basic Steel Products	2	407.23	44.60	451.83	1.391	0.468	1.859	971.1	10170.1	9.549	0.183
291	Petroleum Refining	3	369.06	17.47	386.53	1.260	0.184	1.444	416.9	4745.0	8.796	0.304
333	Primary Nonferrous Metals	4	79.43	46.92	126.35	0.271	0.493	0.764	243.9	1381.5	17.655	0.553
262	Papermills, Except Bldg. Paper	5	135.97	12.78	148.75	0.464	0.134	0.598	248.0	2356.3	10.525	0.254
324	Cement, Hydraulic	6	129.12	7.50	136.61	0.441	0.079	0.520	190.5	812.3	23.452	0.640
263	Paperboard Mills	7	120.64	5.29	125.94	0.412	0.056	0.468	172.3	1508.8	11.420	0.310
282	Plastics Materials & Synthetics	8	97.59	8.95	106.54	0.333	0.094	0.427	164.6	3798.6	4.333	0.112
371	Motor Vehicles & Equip.	9	55.33	12.80	68.13	0.189	0.134	0.323	224.2	13666.1	1.640	0.024
327	Concrete, Gypsum & Plaster Products	10	63.08	2.31	65.39	0.215	0.024	0.239	130.2	2478.0	5.254	0.097
322	Glass, Glassware, Pressed and Blown	11	49.54	3.52	53.07	0.169	0.037	0.206	103.6	1501.1	6.902	0.137
335	Nonferrous Rolling & Drawing	12	32.17	8.39	40.56	0.110	0.088	0.198	130.0	3324.9	3.910	0.060
332	Iron & Steel Foundries	13	40.03	5.82	45.85	0.137	0.061	0.198	166.1	2631.0	6.313	0.075
325	Structural Clay Prods.	14	46.38	1.29	47.67	0.158	0.013	0.171	81.0	611.9	13.237	0.280
209	Misc. Food & Kindred Prods.	15	36.33	4.01	40.34	0.124	0.042	0.166	98.4	2948.7	3.337	0.056
204	Grain Mill Products	16	33.93	3.88	37.81	0.116	0.041	0.157	87.6	2881.9	3.040	0.055
202	Dairy Products	17	32.45	4.07	36.52	0.111	0.043	0.154	116.7	3466.4	3.367	0.044
372	Aircraft & Parts	18	17.47	8.40	25.87	0.060	0.088	0.148	107.7	11327.0	0.951	0.013
201	Meat Products	19	28.29	4.01	32.31	0.097	0.042	0.139	91.0	3551.0	2.562	0.039
203	Canned, Cured & Frozen Foods	20	30.28	3.14	33.43	0.103	0.033	0.136	85.3	3588.2	2.377	0.038
329	Misc. Nonmetallic Mineral Products	21	27.53	2.96	30.49	0.094	0.031	0.125	74.4	1546.5	4.811	0.081
289	Misc. Chemical Products	22	29.69	1.74	31.43	0.101	0.018	0.119	52.9	1587.1	3.333	0.075
208	Beverages	23	26.95	2.20	29.15	0.092	0.023	0.115	69.7	4790.1	1.455	0.024
206	Sugar	24	31.62	0.28	31.90	0.108	0.003	0.111	40.7	652.0	6.242	0.170
221	Weaving Mills, Cotton	25	10.20	6.87	17.08	0.035	0.072	0.107	63.7	1624.0	3.920	0.066
339	Misc. Primary Metal Products	26	24.65	1.96	26.61	0.084	0.021	0.105	69.6	1131.9	6.150	0.093
344	Fabricated Structural Metal Products	27	18.45	3.52	21.97	0.063	0.037	0.100	86.6	4934.3	1.760	0.020
261	Pulpmills	28	21.72	1.86	23.58	0.074	0.020	0.094	36.9	333.7	11.060	0.212
242	Sawmills & Planing Mills	29	16.24	3.59	19.83	0.055	0.038	0.093	84.7	1783.9	4.750	0.053
226	Textile Finishing, Except Wool	30	22.80	1.29	24.10	0.078	0.014	0.092	46.7	710.0	6.577	0.130
287	Agricultural Chemicals	31	15.01	2.61	17.62	0.051	0.027	0.079	42.5	2745.0	1.550	0.029
353	Construction & Related Machinery	32	13.26	2.91	16.17	0.045	0.031	0.076	57.9	7865.0	0.740	0.010
307	Misc. Plastic Products	33	6.88	4.83	11.71	0.024	0.051	0.075	83.4	2967.7	2.810	0.025
367	Electronic Components and Accessories	34	7.67	4.18	11.85	0.026	0.044	0.070	60.4	4359.2	1.390	0.016
346	Metal Stampings	35	10.86	3.14	14.00	0.037	0.033	0.070	62.4	3030.8	2.060	0.023
295	Paving & Roofing Mat'ls	36	18.57	0.61	19.18	0.063	0.006	0.069	35.1	455.8	7.700	0.151

205	Bakery Products	37	14.46	1.84	16.30	0.049	0.019	0.069	53.0	6466.5	0.820	0.011
264	Misc. Converted Paper Products	38	12.43	2.41	14.84	0.043	0.025	0.068	46.6	6210.1	0.750	0.011
356	General Industrial Machinery	39	11.64	2.67	14.31	0.040	0.028	0.068	57.1	6923.0	0.825	0.010
366	Communication Equipments	40	7.76	3.77	11.53	0.027	0.040	0.066	53.4	6992.5	0.764	0.010
265	Paperboard Containers & Boxes	41	12.43	2.16	14.59	0.042	0.023	0.065	49.6	5937.3	0.840	0.011
362	Electrical Industrial Appar.	42	8.41	3.45	11.86	0.029	0.036	0.065	45.1	4623.7	0.980	0.014
354	Metalworking Machinery	43	9.84	2.76	12.60	0.034	0.029	0.063	61.0	7511.5	0.812	0.008
283	Drugs	44	12.06	1.83	13.89	0.041	0.019	0.060	36.3	5301.6	0.685	0.011
321	Flat Glass	45	14.49	0.99	15.48	0.050	0.010	0.060	28.7	422.9	6.780	0.142
349	Misc. Fabricated Metal Products	46	10.40	2.03	12.43	0.036	0.021	0.057	49.1	4756.6	1.030	0.010
225	Knitting Mills	47	10.39	1.71	12.10	0.036	0.018	0.054	38.0	4519.3	0.840	0.012
275	Commercial Printing	48	7.05	2.44	9.49	0.024	0.026	0.050	51.4	3944.4	1.300	0.013
243	Millwork, Plywood, Related Products	49	7.54	2.15	9.69	0.026	0.023	0.048	40.8	3653.2	1.110	0.013
336	Nonferrous Foundries	50	9.72	1.42	11.14	0.033	0.015	0.048	37.5	1067.5	3.510	0.045
266	Bldg. Paper & Board Mills	51	9.79	1.36	11.15	0.033	0.014	0.048	23.4	183.7	12.740	0.256
241	Logging Camps & Contractors	52	13.50	0.13	13.63	0.046	0.001	0.047	43.1	695.1	6.200	0.068
284	Soap, Cleaners, Toilet Goods	53	10.93	0.90	11.84	0.037	0.010	0.047	27.6	6511.2	0.424	0.007
249	Misc. Wood Products	54	9.87	1.23	11.10	0.034	0.013	0.046	30.8	730.3	4.100	0.063
347	Metal Services, N.E.C.	55	7.78	1.15	8.92	0.027	0.012	0.039	38.2	864.3	4.400	0.045
286	Gum & Wood Chemicals	56	5.43	0.82	6.25	0.019	0.009	0.028	8.2	100.8	8.130	0.278
326	Pottery & Related Products	57	6.43	0.43	6.86	0.022	0.005	0.027	15.9	418.7	3.800	0.065
328	Cut Stone & Stone Products	58	1.24	0.22	1.46	0.004	0.002	0.006	5.0	148.2	3.370	0.041
223	Weaving & Finishing Mills, Wool	59	2.77	0.13	2.90	0.010	0.001	0.011	16.5	428.6	3.830	0.026
279	Printing Trade Services	60	0.53	0.20	0.73	0.002	0.002	0.004	5.9	543.7	1.090	0.007

*Equiv. = Equivalent

TABLE A-5

RANKING BY TOTAL FUEL AND ELECTRIC ENERGY PURCHASED (3-DIGIT SIC GROUPING) 1971

SIC CODE	INDUSTRY GROUP	RANK	Purchased Fuel (10^9 kWh Equiv.^{a})	Purchased Electric Energy (10^9 kWh)	Total Purchased Energy (10^9 kWh Equiv.)	Purchased Fuel (10^{15} Btu)	Purchased Electric Energy (10^{15} Btu)	Total Purchased Energy (10^{15} Btu)	Total Energy Cost ($\$10^6$)	Value Added by Manufacture ($\$10^6$)	Energy Cost/ Value Added (c/$)	Energy/ Value Added (10^6 Btu/$)
281	Industrial Chemicals	1	504.2	75.4	579.6	1.72	0.79	2.51	1,115.9	9,232.5	12.1	0.27
331	Blast Furnace, Basic Steel Products	2	395.5	49.9	445.4	1.35	0.52	1.87	1,266.1	11,620.5	10.9	0.16
291	Petroleum Refining	3	422.3	22.5	444.8	1.44	0.24	1.68	585.7	4,594.7	12.8	0.365
333	Primary Nonferrous Metal	4	8.13	49.0	130.3	0.278	0.514	0.792	320.1	1,705.6	18.8	0.465
262	Papermills, Except Bldg. Paper	5	154.3	17.0	171.3	0.527	0.178	0.705	375.8	2,909.3	12.9	0.242
282	Plastic Materials and Synthetics	6	118.7	13.6	132.4	0.405	0.142	0.548	286.5	4,936.0	5.8	0.110
324	Cement, Hydraulic	7	125.9	8.5	134.4	0.430	0.089	0.519	243.1	1,157.7	21.0	0.449
263	Paperboard Mills	8	128.0	6.7	134.7	0.437	0.070	0.437	257.1	1,705.6	12.9	0.255
371	Motor Vehicles and Equipment	9	57.2	16.0	73.2	0.195	0.168	0.363	305.0	N.A.	N.A.	N.A.
327	Concrete, Gypsum, Plaster Products	10	72.4	3.2	75.6	0.247	0.034	0.281	180.2	3,842.3	4.7	0.073
322	Glass, Glassware, Pressed & Blown	11	56.7	4.9	61.7	0.194	0.052	0.246	146.7	2,341.1	6.3	0.105
335	Nonferrous Rolling and Drawing	12	37.0	9.9	46.9	0.126	0.104	0.230	173.4	3,798.6	4.6	0.061
332	Iron and Steel Foundries	13	38.5	7.9	46.4	0.131	0.083	0.214	207.3	3,480.7	6.0	0.062
209	Misc. Foods & Kindred Products	14	42.2	5.4	47.6	0.144	0.056	0.200	135.7	N.A.	N.A.	N.A.
204	Grain Mill Products	15	37.6	5.1	42.7	0.128	0.053	0.181	115.7	N.A.	N.A.	N.A.
201	Meat Products	16	33.3	5.9	39.3	0.114	0.062	0.176	130.2	N.A.	N.A.	N.A.
329	Misc. Nonmetallic Mineral Products	17	35.4	4.2	39.6	0.121	0.046	0.165	108.2	2,359.9	4.6	0.07
203	Canned, Cured & Frozen Foods	18	34.2	4.5	38.7	0.116	0.048	0.165	119.8	N.A.	N.A.	N.A.
372	Aircraft & Parts	19	17.5	8.5	26.1	0.597	0.089	0.149	124.5	N.A.	N.A.	N.A.
202	Dairy Products	20	28.5	4.9	33.4	0.097	0.051	0.148	123.2	N.A.	N.A.	N.A.
325	Structural Clay Prod.	21	39.0	1.3	40.3	0.133	0.014	0.147	82.2	771.1	10.7	0.191
307	Misc. Plastic Products	22	17.3	8.2	25.5	0.059	0.086	0.144	133.7	N.A.	N.A.	N.A.
208	Beverages	23	31.2	3.6	34.8	0.106	0.037	0.144	104.8	N.A.	N.A.	N.A.
206	Sugar	24	38.3	0.4	38.7	0.131	0.004	0.135	61.7	N.A.	N.A.	N.A.
289	Misc. Chemical Prod.	25	31.7	2.5	34.2	0.108	0.026	0.134	76.0	2,357.3	3.2	0.057
242	Sawmills & Planing Mills	26	20.7	5.2	25.9	0.071	0.055	0.126	130.7	N.A.	N.A.	N.A.
344	Fabricated Structural Metal Products	27	19.9	4.5	24.4	0.068	0.048	0.116	104.5	7,028.3	1.5	0.016
339	Misc. Primary Metal Products	28	25.3	2.5	27.9	0.086	0.027	0.113	80.5	1,243.3	6.5	0.091
301	Tires & Inner Tubes	29	19.6	4.1	23.7	[illegible]	0.067	0.043	69.0	N.A.	N.A.	N.A.
261	Pulp Mills	30	23.8	2.5	26.2	0.081	0.026	0.107	57.9	306.8	18.9	0.350
287	Agricultural Chemicals	31	21.1	2.9	24.0	0.072	0.031	0.103	52.6	1,741.9	3.0	0.059
226	Textile Finishing, Except Wool	32	23.7	1.6	25.3	0.081	0.017	0.098	65.7	1,120.2	5.9	0.087
264	Misc. Converted Paper Products	33	16.4	3.9	20.3	0.056	0.041	0.097	73.3	4,005.8	1.8	0.024
353	Construction & Related Machinery	34	15.2	3.6	18.8	0.0380	0.052	0.090	70.9	N.A.	N.A.	N.A.

222	Weaving Mills, Synthetics	35	9.2	5.6	14.8	0.031	0.058	0.089	63.7	1,831.6	3.5	0.049
265	Paperboard Containers and Boxes	36	16.3	3.2	19.5	0.056	0.033	0.089	73.0	3,599.3	2.0	0.025
221	Weaving Mills, Cotton	37	8.8	5.4	14.2	0.057	0.030	0.087	60.7	1,256.3	4.8	0.069
283	Drugs	38	16.7	2.8	19.5	0.057	0.029	0.086	63.1	6,132.0	1.0	0.014
367	Electronic Components Accessories	39	9.0	5.1	14.2	0.031	0.054	0.085	77.8	N.A.	N.A.	N.A.
205	Bakery Products	40	16.2	2.8	18.9	0.084	0.055	0.079	66.4	N.A.	N.A.	N.A.
225	Knitting Mills	41	14.3	3.1	17.4	0.049	0.033	0.082	66.8	3,180.5	2.1	0.026
349	Miscellaneous Fabricated Metal Products	42	14.3	3.1	17.4	0.049	0.033	0.082	69.4	5,109.5	1.4	0.016
356	General Industrial Machinery	43	13.4	3.4	17.4	0.046	0.036	0.082	74.6	N.A.	N.A.	N.A.
366	Communication Equip.	44	8.6	4.8	13.4	0.029	0.051	0.080	73.5	N.A.	N.A.	N.A.
346	Metal Stampings	45	11.6	3.8	15.5	0.039	0.040	0.079	76.3	4,291.3	1.8	0.018
362	Electrical Industrial Apparatus	46	10.0	4.3	14.3	0.034	0.045	0.079	63.9	N.A.	N.A.	N.A.
275	Commercial Printing	47	10.5	4.1	14.6	0.036	0.043	0.079	80.9	N.A.	N.A.	N.A.
354	Metalworking Machin.	48	11.5	3.3	14.9	0.039	0.034	0.073	73.8	N.A.	N.A.	N.A.
243	Millwork, Plywood, Related Products	49	10.7	3.2	13.9	0.037	0.033	0.070	58.2	N.A.	N.A.	N.A.
295	Paving & Roofing Materials	50	17.4	0.9	18.3	0.059	0.009	0.069	44.0	866.9	5.2	0.081
321	Flat Glass	51	16.4	0.9	17.3	0.056	0.010	0.066	34.5	662.3	5.2	0.099
249	Miscellaneous Wood Products	52	12.0	2.2	14.2	0.041	0.023	0.064	50.2	N.A.	N.A.	N.A.
284	Soap, Cleaners and Toilet Goods	53	14.2	1.4	15.6	0.048	0.015	0.063	46.7	6,203.3	0.8	0.010
266	Bldg. Paper and Board Mills	54	11.6	1.6	13.2	0.040	0.017	0.056	35.5	N.A.	N.A.	N.A.
336	Nonferrous Foundries	55	10.3	1.6	12.0	0.035	0.017	0.052	43.1	1,269.2	3.4	0.041
347	Metal Services, Nec.	56	8.8	1.9	10.8	0.030	0.020	0.050	45.6	1,124.3	4.1	0.045
341	Logging Camps, Contractors	57	13.2	0.2	13.5	0.045	0.002	0.047	48.2	N.A.	N.A.	N.A.
326	Pottery and Related Products	58	7.0	0.6	7.6	0.026	0.006	0.03	19.4	400.7	3.2	0.049
223	Weaving and Finishing Wool Mills	59	3.1	0.51	3.6	0.011	0.005	0.016	12.6	239.4	5.3	0.067
286	Gum and Wood Chemicals	60	2.7	0.2	2.9	0.009	0.002	0.010	6.6	155.4	4.2	0.071
328	Cut Stone and Stone Products	61	1.1	0.4	1.5	0.004	0.004	0.008	5.6	191.4	2.9	0.041
279	Printing Trade Serv.	62	0.6	0.4	1.0	0.002	0.004	0.006	7.8	N.A.	N.A	N.A
303	Reclaimed Rubber	63	0.3	0.1	0.4	0.001	0.001	0.002	1.9	N.A.	N.A.	N.A.

*Equiv. = Equivalent

TABLE A-6

RANKING BY FUEL AND ELECTRIC ENERGY PURCHASED (4-DIGIT SIC GROUPING) 1954

SIC CODE	INDUSTRY GROUP	RANK	Purchased Fuel (10^9 kWh Equiv.*)	Purchased Electric Energy (10^9 kWh)	Total Purchased Energy (10^9 kWh Equiv.)	Purchased Fuel (10^{15} Btu)	Purchased Electric Energy (10^{15} Btu)	Total Purchased Energy (10^{15} Btu)	Total Energy Cost ($\$10^6$)	Value Added by Manufacture ($\$10^6$)	Energy Cost/ Value Added (c/$)	Energy/ Value Added (10^6 Btu/$)
3312	Blast Furnace & Steel Mills	1	1487.9	14.1	1502.0	5.08	0.1477	5.228	1349.0	4640.5	29.07	1.1265
2911	Petroleum Refining	2	172.4	5.6	178.0	0.589	0.0586	0.6476	135.1	1901.3	7.11	0.3406
2611	Pulp Mills	3	148.6	8.6	157.7	0.507	0.0905	0.5979	NA	704.2	NA	NA
2819	Inorganic Chemicals n.e.c.	4	33.6	30.8	64.4	0.115	0.3233	0.4381	263.3	1069.3	24.6	0.4097
3241	Cement Hydraulic	5	107.0	3.6	110.6	0.365	0.0383	0.4035	128.7	528.9	24.3	0.7629
2829	Organic Chemicals, n.e.c	6	77.7	3.5	81.2	0.265	0.0366	0.3019	74.9	1171.1	6.4	0.2578
3334	Primary Aluminum	7	34.0	17.2	51.2	0.116	0.181	0.297	63.4	264.2	27.07	1.1241
2825	Synthetic Fiber	8	54.7	0.5	55.2	0.187	0.0049	0.1919	27.3	717.2	3.8	0.2673
3717	Motor Vehicles	9	36.4	5.6	42.0	0.124	0.0588	0.1831	120.7	6111.5	2.0	0.030
2612	Paper & Paperboard Mills	10	15.7	8.6	24.3	0.054	0.0905	0.1441	NA	NA	NA	NA
2824	Synthetics Rubber	11	34.6	0.4	35.0	0.118	0.0042	0.1222	7.09	152.9	4.6	0.8005
2812	Alkalies & Chlorine	12	24.5	3.3	27.8	0.084	0.0346	0.1183	48.8	251.0	19.4	0.4713
3251	Brick & Hollow Tile	13	28.9	0.4	29.3	0.099	0.004	0.103	35.7	183.3	19.5	0.560
2011	Meat Packing Plants	14	25.1	1.6	26.7	0.0856	0.0166	0.1022	49.4	1394.4	3.5	0.0734
3221	Glass Container	15	22.3	1.0	23.3	0.076	0.0104	0.0864	35.4	377.1	9.5	0.2991
3321	Gray Iron Foundries	16	21.6	1.1	22.7	0.074	0.0113	0.0852	57.5	846.2	6.8	0.1007
2622	Intermediate & Organic Color	17	21.3	0.7	22.0	0.073	0.0075	0.0805	27.9	362.3	7.7	0.2216
2261	Textile Finishing, Except Wool	18	21.3	0.5	21.8	0.0727	0.0054	0.0781	31.9	464.1	6.9	0.1684
2823	Plastics & Materials	19	12.7	2.8	13.5	0.0434	0.0296	0.073	22.3	583.2	3.8	0.1252
3313	Electrometallurgical Products	20	8.2	3.6	11.8	0.028	0.0379	0.0659	21.7	114.7	18.91	0.574
3333	Primary Zinc	21	14.1	1.5	15.6	0.0482	0.0158	0.0639	17.4	87.5	19.88	0.7304
3011	Tires & Inner Tubes	22	13.5	1.5	14.9	0.046	0.0156	0.0613	24.5	844.5	2.9	0.0725
2421	Sawmills & Planing Mills	23	9.9	2.0	11.9	0.034	0.0207	0.0547	54.7	1502.9	3.64	0.0362
2051	Bread & Related Prod.	24	13.0	1.0	14.0	0.0443	0.010	0.0543	40.1	1568.9	2.56	0.0346
2094	Wet Corn Milling	25	14.2	0.07	14.3	0.0485	0.0008	0.0493	11.0	176.6	6.2	0.2792
3031	Reclaimed Rubber	26	9.7	1.4	11.1	0.0332	0.0144	0.0476	28.4	930.1	3.06	0.0511
2826	Explosives	27	12.7	0.3	13.0	0.0434	0.0036	0.0470	11.0	205.4	5.33	0.2288
3391	Iron & Steel Forgings	28	12.0	0.5	12.5	0.0411	0.0051	0.0461	24.03	304.2	7.9	0.1515
2082	Beer and Ale	29	11.3	0.6	11.9	0.0385	0.006	0.0445	19.7	1100.7	1.8	0.0404
2021	Creamery Butter	30	12.2	0.2	12.4	0.0416	0.0024	0.0417	11.9	136.9	8.7	0.3215
2613	Bldg. Paper & Board Mills	31	9.9	0.7	10.6	0.0338	0.0077	0.0415	15.7	155.4	10.1	0.267
3229	Pressed & Blown Glass	32	10.5	0.5	11.1	0.036	0.0054	0.0414	19.8	297.2	6.65	0.1391
2033	Canned Fruits & Veg.	33	10.4	0.4	10.8	0.0355	0.0041	0.0396	20.0	830.0	2.41	0.0477
3721	Aircraft	34	4.6	2.0	6.6	0.0156	0.021	0.0366	24.5	844.5	2.90	0.0522
2023	Concentrated Milk	35	9.2	0.4	9.6	0.0316	0.0046	0.0362	11.9	170.6	7.0	0.2122
3722	Aircraft & Engines	36	5.9	1.4	7.3	0.0201	0.0145	0.0346	27.4	1435.4	1.91	0.0547
2491	Wood Preserving	37	9.4	0.05	9.5	0.032	0.0005	0.0325	3.6	69.3	5.17	0.4693
2062	Cane Sugar Refining	38	9.4	0.01	9.4	0.0321	0.0001	0.0322	9.0	139.0	6.46	0.232
3254	Sewer Pipes	39	8.0	0.06	8.1	0.0274	0.0006	0.0281	8.5	55.3	15.4	0.5073
3255	Clay Refractories	40	7.0	0.14	7.1	0.024	0.0015	0.0253	9.8	88.7	11.03	0.0495
2085	Distilled Liquor	41	6.8	0.13	6.9	0.0232	0.0014	0.0246	7.7	356.7	2.16	0.0478

*Equiv. = Equivalent

TABLE A-7

RANKING BY FUEL AND ELECTRIC ENERGY PURCHASED (4-DIGIT SIC GROUPING) 1958

SIC CODE	INDUSTRY GROUP	RANK	Purchased Fuel (10^9 kWh Equiv.)	Purchased Electric Energy (10^9 kWh)	Total Purchased Energy (10^9 kWh Equiv.)	Purchased Fuel (10^{15} Btu)	Purchased Electric Energy (10^{15} Btu)	Total Purchased Energy (10^{15} Btu)	Total Energy Cost ($\$10^6$)	Value Added by Manufacture ($\$10^6$)	Energy Cost/ Value Added (c/$)	Energy/ Value Added (10^6 Btu/$)
3312	Blast Furnaces and Steel Mills	1	314.5	16.4	330.9	1.074	0.172	1.246	676.24	6042.2	11.15	0.206
2911	Petroleum Refining	3	250.9	9.1	260.0	0.857	0.096	0.953	240.0	2119.4	11.32	0.450
2819	Inorganic Chemicals n.e.c.	2	82.7	67.7	150.4	0.282	0.711	0.993	361.1	1468.9	24.58	0.676
3241	Cement, Hydraulic	4	110.1	5.0	115.1	0.376	0.053	0.429	161.5	724.8	22.28	0.592
2621	Papermills, Except Bldg. Paper	5	104.9	6.2	111.1	0.358	0.065	0.423	166.0	1541.8	10.76	0.274
2818	Organic Chemicals n.e.c.	6	97.7	4.6	102.3	0.334	0.048	0.382	111.9	1671.7	6.69	0.229
2631	Paperboard Mills	7	78.4	2.5	80.9	0.268	0.026	0.294	109.3	840.1	13.0	0.350
3717	Motor Vehicles and Parts	9	41.1	6.8	47.9	0.141	0.072	0.213	140.2	6473.9	2.17	0.033
3334	Primary Aluminum	8	30.4	16.2	46.6	0.104	0.170	0.274	79.2	383.8	20.64	0.714
2812	Alkalies and Chlorine	10	41.4	4.1	45.5	0.141	0.043	0.184	62.4	306.2	20.37	0.601
2815	Cyclic Intermediates and Crudes	11	27.1	1.0	28.0	0.093	0.010	0.103	27.1	373.1	7.26	0.276
2823	Cellulosic Man-Made Fibres	14	26.8	0.3	27.1	0.092	0.003	0.095	26.4	390.3	6.76	0.243
3221	Glass Containers	12	24.8	1.3	26.1	0.085	0.014	0.099	45.5	810.8	5.61	0.122
2821	Plastic Materials and Resins	15	22.9	1.6	24.5	0.078	0.017	0.095	40.9	872.0	4.69	0.109
2011	Meat Packing Plants	16	22.2	1.7	23.9	0.076	0.018	0.094	48.1	1746.6	2.76	0.054
3251	Brick and Structural Tile	18	23.0	0.5	23.6	0.079	0.005	0.084	38.2	196.9	19.42	0.427
2026	Fluid Milk	19	18.5	2.0	20.5	0.063	0.021	0.084	60.5	1990.8	3.04	0.042
2211	Weaving Mill Cotton	13	11.9	5.2	17.1	0.041	0.055	0.096	55.8	1078.6	5.18	0.089
2051	Bread & Related Products	20	18.1	1.0	19.1	0.062	0.011	0.073	53.6	2111.8	2.54	0.345
3321	Gray Iron Foundries	21	14.7	1.1	15.8	0.050	0.012	0.062	58.2	810.8	7.18	0.077
3313	Electrometallurgical Products	17	10.0	4.8	14.8	0.034	0.051	0.085	30.5	178.9	17.07	0.475
3274	Lime	24	13.9	0.3	14.3	0.048	0.003	0.051	22.1	73.6	30.04	0.693
2046	Wet Corn Milling	25	13.9	0.2	14.1	0.048	0.002	0.050	13.6	249.4	5.38	0.201
2063	Beet Sugar	27	14.0	0.1	14.1	0.048	0.001	0.049	16.8	130.6	12.9	0.376
3331	Primary Copper	23	12.9	0.7	13.7	0.044	0.008	0.052	21.8	158.1	13.76	0.329
2661	Bldg. Paper & Board Mills	22	12.3	1.2	13.5	0.042	0.013	0.055	26.5	215.1	12.31	0.256
2261	Finishing Plants, Cotton	29	12.6	0.4	13.0	0.043	0.004	0.047	22.4	289.1	7.73	0.163
2611	Pulp Mills	28	12.4	0.6	13.0	0.042	0.006	0.048	25.3	196.0	12.89	0.245
3211	Flat Glass	31	11.8	0.6	12.4	0.040	0.006	0.046	19.0	263.2	7.21	0.175
3391	Iron & Steel Forgings	33	11.4	0.5	11.9	0.039	0.005	0.044	26.0	310.2	8.38	0.142
2082	Malt Liquors	32	11.2	0.6	11.8	0.038	0.007	0.045	21.0	1116.6	1.88	0.040
2421	Saw Mills & Planing Mills (General)	26	9.4	1.7	11.1	0.032	0.018	0.050	60.0	1196.7	5.02	0.042
3229	Pressed & Blown Glass, n.e.c.	34	10.2	0.6	10.8	0.035	0.006	0.041	21.6	312.3	6.92	0.131

2816	Inorganic Pigments	35	10.1	0.4	10.5	0.035	0.004	0.039	15.5	235.7	6.57	0.166
2033	Canned Fruits & Vegetables	37	10.0	0.4	10.3	0.034	0.004	0.038	20.3	808.3	2.51	0.047
3352	Aluminum Rolling and Drawing	30	7.5	2.0	9.5	0.026	0.021	0.047	30.4	537.1	5.65	0.088
2062	Cane Sugar Refining	39	9.5	0.02	9.5	0.032	0.0002	0.034	11.2	184.8	6.07	0.184
3333	Primary Zinc	35	7.1	1.4	8.5	0.024	0.015	0.039	19.5	71.7	27.23	0.544
3351	Copper Rolling and Drawing	38	7.3	1.0	8.3	0.025	0.010	0.035	22.3	445.4	5.0	0.079
3721	Aircraft	40	3.6	2.1	5.7	0.012	0.022	0.034	25.6	3399.2	0.75	0.010

*Equiv. = Equivalent

TABLE A-8

RANKING BY FUEL AND ELECTRIC ENERGY PURCHASED (4-DIGIT SIC GROUPING) 1962

SIC CODE	INDUSTRY GROUP	RANK	Purchased Fuel (10^9 kWh Equiv.)	Purchased Electric Energy (10^9 kWh)	Total Purchased Energy (10^9 kWh Equiv.)	Purchased Fuel (10^{15} Btu)	Purchased Electric Energy (10^{15} Btu)	Total Purchased Energy (10^{15} Btu)	Total Energy Cost ($\$10^6$)	Value Added by Manufacture ($\$10^6$)	Energy Cost/ Value Added (c/$)	Energy/ Value Added (10^6 Btu/$)
3312	Blast Furnaces and Steel Mills	1	316.2	22.6	340.8	1.086	0.2372	1.3237	809.4	7,699.5	10.51	0.1719
2911	Petroleum Refining	2	311.3	12.1	323.4	1.063	0.1275	1.1905	336.9	3,137.6	10.74	0.3794
2819	Inorganic Chemicals Nec.	3	99.6	62.0	161.6	0.340	0.6512	0.9913	365.1	1,902.6	19.19	0.5210
2818	Organic Chemicals, Nec.	4	152.0	7.4	159.4	0.5192	0.0772	0.5964	173.5	2,727.5	6.36	0.2187
3241	Cement, Hydraulic	5	121.2	5.9	127.1	0.4139	0.0621	0.4760	172.0	785.7	21.89	0.6059
2621	Papermills, Except Building Paper	6	113.1	8.3	121.4	0.3862	0.0871	0.6733	197.5	1,857.2	10.63	0.2548
3334	Primary Aluminum	7	33.5	26.9	60.4	0.1144	0.2823	0.3967	116.4	499.6	23.3	0.7939
2631	Paperboard Mills	8	85.3	3.2	88.5	0.2914	0.0335	0.3249	122.1	1,186.2	10.29	0.2739
3717	Motor Vehicles and Parts	9	40.4	9.9	50.3	0.1378	0.1039	0.2417	180.3	12,345.6	1.46	0.0196
2812	Alkalies and Chlorine	10	48.4	6.2	54.6	0.1652	0.0646	0.2298	78.4	389.2	20.14	0.5905
2815	Cyclic Intermediates and Crudes	11	23.2	1.6	24.8	0.0792	0.0166	0.1265	37.0	570.2	6.49	0.2218
3313	Electrometallurgical Products	12	18.6	5.4	24.0	0.0636	0.0570	0.1206	48.2	145.5	33.13	0.08289
3221	Glass Containers	13	28.1	1.7	29.8	0.0959	0.0176	0.1135	55.8	629.6	8.86	0.1802
2821	Plastics Materials	14	22.2	2.3	24.5	0.0758	0.0240	0.0999	47.8	1,202.3	3.98	0.0831
2211	Weaving Mills, Cotton	15	10.6	5.9	16.5	0.03611	0.062	0.0981	57.7	1,256.8	4.59	0.0781
2823	Cellulosic Manmade Fibers	16	25.2	0.3	25.5	0.0861	0.0035	0.0896	23.0	411.5	5.59	0.2177
2011	Meat Packing Prod.	17	19.9	2.1	22.0	0.0679	0.0215	0.0894	54.3	1,908.3	2.84	0.0469
3321	Gray Iron Foundries	18	18.9	1.6	20.5	0.0646	0.0164	0.09097	55.8	1,168.5	4.76	0.0693
3251	Brick & Structural Tile	19	21.8	0.6	22.4	0.0745	0.0060	0.0804	43.7	216.5	20.18	0.3716
2026	Fluid Milk	20	15.9	2.2	18.1	0.0544	0.0233	0.0776	66.9	2,703.2	3.04	0.0352
3011	Tires and Inner Tubes	21	15.8	2.2	18.0	0.0540	0.0227	0.0767	35.6	1,321.7	2.69	0.0580
2611	Pulp Mills	22	18.9	1.1	20.1	0.0647	0.0119	0.0766	30.0	295.8	10.14	0.2592
2661	Building Paper and Board Mills	23	14.9	1.4	16.3	0.0510	0.0149	0.0659	30.7	153.1	20.05	0.4305
3331	Primary Copper	24	15.9	1.0	16.9	0.0544	0.0102	0.0646	27.4	285.5	9.6	0.2261
2421	Sawmills and Planing Mills	25	11.9	2.1	14.0	0.0406	0.0222	0.0628	67.6	1,376.1	4.91	0.0456
3352	Aluminum Rolling and Drawing	26	9.9	2.5	12.4	0.0339	0.0262	0.0601	38.8	721.2	5.38	0.0833
2063	Beet Sugar	27	16.8	0.07	16.8	0.0573	0.0007	0.05797	19.9	200.7	9.92	0.2889
3333	Primary Zinc	28	12.3	1.4	13.7	0.0419	0.0143	0.0562	18.8	98.8	19.03	0.5694
3229	Pressed and Blown Glass, Nec.	29	13.1	0.9	14.0	0.0446	0.0091	0.0537	30.4	472.2	6.44	0.1132
2046	Wet Corn Milling	30	15.0	0.2	15.2	0.0512	0.0023	0.0535	15.2	290.9	5.23	0.1837
3211	Flat Glass	31	12.8	0.8	13.6	0.0436	0.0087	0.0523	23.6	364.5	6.47	0.1435
2813	Industrial Gases	32	4.2	3.5	7.7	0.0144	0.0367	0.0511	37.0	260.1	14.22	0.1965

2261	Finishing Plants, Cotton	33	13.0	0.5	13.5	0.0443	0.0053	0.0496	23.4	332.3	7.06	0.1493
3079	Plastic Products, Nec.	34	6.9	2.4	9.3	0.0237	0.0249	0.0485	48.3	1,660.9	2.91	0.0292
3721	Aircraft	35	5.9	2.5	8.4	0.0202	0.0260	0.0462	31.5	3,542.7	0.889	0.0130
2082	Malt Liquors	36	10.1	0.8	10.9	0.0344	0.0084	0.0429	21.8	1,288.0	1.70	0.0333
3391	Iron and Steel Forgings	37	10.8	0.6	11.4	0.0368	0.0058	0.0427	31.4	395.3	7.94	0.1079
2816	Inorganic Pigments	38	10.3	0.6	10.9	0.0350	0.0063	0.0413	20.6	286.4	7.19	0.1443
2033	Canned Fruit and Vegetables	39	10.4	0.5	10.9	0.0354	0.0059	0.0413	25.2	1,029.5	2.45	0.0401
2099	Food Preparations, Nec.	40	8.0	0.6	8.6	0.0272	0.0067	0.0339	24.1	849.6	2.84	0.0399

*Equiv. = Equivalent

TABLE A-9

RANKING BY FUEL AND ELECTRIC ENERGY PURCHASED (4-DIGIT SIC GROUPING) 1967

SIC CODE	INDUSTRY GROUP	RANK	Purchased Fuel (10^9 kWh Equiv.*)	Purchased Electric Energy (10^9 kWh)	Total Purchased Energy (10^9 kWh Equiv.)	Purchased Fuel (10^{15} Btu)	Purchased Electric Energy (10^{15} Btu)	Total Purchased Energy (10^{15} Btu)	Total Energy Cost ($\$10^6$)	Value Added by Manufacture ($\$10^6$)	Energy Cost/ Value Added (c/$)	Energy/ Value Added (10^6 Btu/$)
3312	Blast Furnaces and Steel Mills	1	388.81	34.794	415.608	1.3004	.3653	1.6658	877.3	8,910.1	9.846	.1870
2911	Petroleum Refining	2	369.059	17.474	386.533	1.2603	.1834	1.4438	416.9	4,745.0	8.786	.3043
2819	Industrial Inorganic Chemicals, Nec.	3	129.274	45.924	176.198	.4414	.4822	.9236	339.7	2,295.4	14.80	.4024
2818	Industrial Organic Chem. Nec.	4	219.164	13.378	232.542	.7484	.1405	.8889	263.6	3,575.3	7.373	.2486
2621	Papermills, except Building Paper	5	135.972	12.776	148.749	.4643	.13415	.5985	248.0	2,356.3	15.25	.2540
3334	Primary Aluminum	6	44.352	41.956	86.309	.1514	.44054	.5920	176.8	811.8	21.78	.7293
3241	Cement, Hydraulic	7	129.115	7.495	136.610	.4409	.0787	.5196	190.5	812.3	23.45	.6397
2631	Paperboard Mills	8	120.644	5.294	125.938	.4121	.0559	.4676	172.3	1,508.8	11.42	.3100
2812	Alkalies and Chlorine	9	45.123	9.298	54.421	.1541	.0976	.2517	96.0	410.2	22.90	.6005
3711	Motor Vehicles - Passenger Car Bodies	10	28.955	5.714	34.669	.0988	.0599	.1588	105.2	7,353.6	1.43	.0216
2821	Plastic Materials and Resins	11	31.666	4.367	36.034	.1081	.0458	.1540	70.1	1,635.1	9.61	.0942
3714	Motor Vehicle Parts and Accesories	12	24.286	6.733	31.020	.0829	.0707	.1536	109.8	5,712.0	1.92	.0269
2815	Cyclic Intermediate & Crudes	13	33.895	2.574	36.469	.1158	.0270	.1427	54.1	729.5	7.416	.1957
3221	Glass Containers	14	32.287	2.329	34.617	.1103	.0244	.1347	66.3	842.2	7.87	.1600
3313	Electrometallurgical Prod.	15	13.803	7.852	21.655	.0471	.0824	.1295	50.5	193.2	26.139	.6707
3321	Gray Iron Foundries	16	25.260	2.805	28.066	.0862	.0294	.1157	102.7	1,543.1	6.655	.0750
2813	Industrial Gases	17	11.914	6.776	18.690	.0406	.0711	.1118	63.6	400.9	15.864	.2790
3562	Ball and Roller Bearing	18	3.3828	.9192	4.3020	.0115	.0965	.10806	16.0	833.3	1.920	.1290
2211	Weaving Mills, Cotton	19	10.204	6.871	17.076	.0348	.0722	.1070	63.7	1,624.0	3.922	.0659
2824	Organic Fibers, Noncellulosic	20	23.181	2.539	25.720	.0791	.0266	.1058	41.3	1,251.8	3.299	.0845
2823	Cellulosic Manmade Fibers	21	28.481	.472	28.954	.0973	.00496	.1022	28.8	506.8	5.68	.2017
3251	Brick and Structural Clay Tile	22	27.283	.702	27.985	.09317	.00737	.10054	44.7	251.1	17.801	.4004
2011	Meat Packing Plants	23	20.514	2.503	23.018	.07005	.0262	.09634	56.7	2,220.5	2.553	.0434
3352	Aluminum Rolling and Drawing	24	15.874	3.863	19.737	.0542	.04055	.0947	54.0	938.7	5.753	.1010
2611	Pulp Mills	25	21.716	1.859	23.575	.0741	.0195	.09368	36.9	333.7	11.058	.2808
2421	Sawmills and Planing Mills, Gen.	26	15.085	3.276	18.361	.0515	.0344	.0859	77.0	1,556.4	4.947	.0552
3011	Tires and Inner Tubes	27	16.7972	2.674	19.472	.0573	.0280	.0854	40.7	1,823.0	2.232	.0469
3274	Lime	28	22.550	.5515	23.062	.0770	.00537	.0823	31.4	100.1	31.369	.8230
3561	Pumps and Compressors	29	3.3948	.6432	4.038	.01159	.0675	.0791	15.3	1,210.2	1.264	.0654
2026	Fluid Milk	30	15.125	2.509	17.634	.05165	.0263	.0780	66.5	2,350.7	2.829	.0332
3273	Ready-mixed Concrete	31	20.825	.5539	21.379	.0711	.0058	.07693	50.0	1,155.5	4.327	.0666
3229	Pressed and Blown Glass. Nec.	32	17.254	1.194	18.449	.0589	.0125	.07147	37.3	658.9	5.661	.1085

3461	Metal Stampings	33	10.863	3.137	14.000	.0371	.0329	.07006	62.6	3,030.8	2.059	.0231
3333	Primary Zinc	34	15.090	1.493	16.583	.0515	.01567	.06721	22.9	119.5	19.163	.5624
2822	Synthetic Rubber	35	14.261	1.570	15.832	.0487	.0165	.0652	24.4	404.9	6.026	.1610
2046	Wet Corn Milling	36	14.491	.9883	15.480	.0052	.0639	.06399	20.3	353.6	6.741	.1810
2063	Beet Sugar	37	17.985	.1104	18.095	.0614	.00115	.06257	22.1	209.7	10.539	.2984
2051	Bread, Cake and Related Products	38	13.5	1.435	13.500	.0461	.0151	.0612	44.2	5,702.7	.8662	.01198
3211	Flat Glass	39	14.491	.988	15.480	.0494	.0103	.0598	28.7	422.9	6.786	.1416
3391	Iron and Steel Forgings	40	14.858	.745	15.604	.0507	.00783	.0585	34.7	607.4	6.713	.0964

*Equiv. = Equivalent

TABLE A-10

RANKING BY FUEL AND ELECTRIC ENERGY PURCHASED (4-DIGIT SIC GROUPING) 1971

SIC CODE	INDUSTRY GROUP	RANK	Purchased Fuel (10^9 kWh Equiv.*)	Purchased Electric Energy (10^9 kWh)	Total Purchased Energy (10^9 kWh Equiv.)	Purchased Fuel (10^{15} Btu)	Purchased Electric Energy (10^{15} Btu)	Total Purchased Energy (10^{15} Btu)	Total Energy Cost ($\$10^6$)	Value Added by Manufacture ($\$10^6$)	Energy Cost/ Value Added (¢/$)	Energy/ Value Added (10^6 Btu/$)
3312	Blast Furnaces and Steel Mills	1	367.9	40.26	408.2	1.2560	0.423	1.6791	1,152.2	10,304.7	11.2	0.163
2911	Petroleum Refining	2	422.3	22.52	444.8	1.4420	0.2365	1.6786	585.7	4,594.7	12.8	0.365
(2869) 2818	Industrial Organic Chemicals Nec.	3	266.3	19.70	286.0	0.9090	0.2068	1.116	402.2	4,965.1	8.1	0.225
2819	Industrial Inorganic Chemicals	4	132.8	33.46	166.3	0.4535	0.3513	0.8048	392.7	2,037.3	19.3	0.395
2621	Paper Mills, Except Building Paper	5	154.3	16.96	171.3	0.5269	0.1780	0.705	375.8	2,909.3	12.9	0.242
3334	Primary Aluminum	6	41.9	42.71	84.6	0.1431	0.4485	0.592	216.8	816.0	26.6	0.725
3241	Cement Hydraulic	7	125.9	8.51	134.4	0.4299	0.894	0.519	243.1	1,157.7	21.0	0.449
2631	Paperboard Mills	8	128.0	6.74	134.7	0.4371	0.0708	0.508	257.1	1,994.6	12.9	0.255
2812	Alkalies & Chlorine	9	40.9	9.14	50.0	0.1397	0.096	0.236	111.4	455.6	24.5	0.517
2821	Plastic Materials and Resins	10	39.3	6.36	45.7	0.1342	0.0668	0.201	119.9	2,160.5	5.6	0.093
3714	Motor Vehicles, Parts and Accessories	11	27.8	8.81	36.6	0.0949	0.0925	0.187	159.1	N.A.	N.A.	N.A.
2824	Organic Fibers, Noncellulosic	12	38.6	4.84	43.4	0.1318	0.0509	0.183	95.8	2,031.1	4.7	0.090
3221	Glass Containers	13	38.2	3.40	41.6	0.1305	0.0357	0.166	97.8	1,399.7	7.0	0.119
(2865) 2815	Cyclic Intermediates and Crudes	14	37.0	3.32	40.3	0.1264	0.0349	0.1613	91.4	925.2	9.9	0.174
3711	Motor Vehicles	15	26.3	6.68	33.0	0.0898	0.0701	0.156	133.3	N.A.	N.A.	N.A.
2611	Pulp Mills	16	23.8	2.50	26.2	0.0813	0.0643	0.1456	57.9	306.8	18.9	0.475
3079	Miscellaneous Plastic Products	17	17.3	8.17	25.5	0.059	0.0898	0.1450	133.7	N.A.	N.A.	N.A.
3313	Electrometallurgical Products	18	16.3	7.69	24.0	0.0557	0.0807	0.136	64.8	217.2	29.8	0.626
2813	Industrial Gases	19	12.6	8.6	21.1	0.0430	0.090	0.133	81.7	466.7	17.5	0.243
3321	Gray Iron Foundries	20	24.8	4.53	29.3	0.0847	0.0476	0.132	135.0	2,256.5	6.0	0.059
3352	Aluminum Rolling and Drawing	21	21.1	4.76	25.9	0.0721	0.05	0.1221	77.9	1,178.5	6.6	0.104
2011	Meat Packing Plants	22	23.1	3.62	26.8	0.0789	0.038	0.117	81.8	N.A.	N.A.	N.A.
2421	Sawmills & Planing Mills, General	23	19.5	4.79	24.3	0.0666	0.050	0.117	56.5	2,850.3	2.0	0.041
3274	Lime	24	26.4	0.62	27.0	0.0901	0.0065	0.097	45.5	131.9	34.5	0.735
3273	Ready-Mixed Concrete	25	23.5	0.99	24.5	0.0802	0.010	0.091	69.2	1,756.7	3.9	0.052
2221	Weaving Mills, Synth.	26	9.2	5.6	14.8	0.031	0.059	0.09	63.7	1,831.6	3.5	0.049
2211	Weaving Mills, Cotton	27	8.8	5.43	14.2	0.03	0.057	0.087	60.7	1,256.3	4.8	0.069
2823	Cellulosic Manmade Fibers	28	23.5	0.51	24.0	0.0803	0.0054	0.086	38.6	252.7	15.3	0.339
2063	Beet Sugar	29	24.2	0.19	24.4	0.0826	0.002	0.085	35.8	N.A.	N.A.	N.A.
3251	Brick and Structural Clay Tiles	30	22.5	0.71	23.2	0.0768	0.0074	0.084	45.6	336.4	13.6	0.25
3331	Primary Copper	31	19.6	1.36	21.0	0.0669	0.0142	0.081	45.5	487.8	9.3	0.166
3461	Metal Stampings	32	11.6	3.82	15.5	0.0396	0.04	0.080	76.3	4,291.3	1.8	0.186
3229	Pressed and Blown Glass NEC	33	18.5	1.56	20.1	0.0632	0.016	0.079	48.9	941.4	5.2	0.085

2822	Synthetic Rubber	34	17.3	1.95	19.2	0.0591	0.020	0.079	32.2	491.7	6.6	0.162
2871	Fertilizers	35	15.9	2.3	18.2	0.054	0.024	0.078	37.5	879.0	4.3	0.09
2026	Fluid Milk	36	12.9	2.81	15.7	0.044	0.03	0.074	65.3	N.A.	N.A.	N.A.
2042	Prepared Feeds for Animals and Fowls	37	13.5	2.25	15.8	0.046	0.024	0.070	50.3	N.A.	N.A.	N.A.
2046	Wet Corn Milling	38	17.9	0.71	18.6	0.061	0.008	0.068	29.5	331.1	8.9	0.207
2051	Bread, Cake and Related Products	39	13.0	2.2	15.2	0.044	0.023	0.067	54.4	N.A.	N.A.	N.A.
3211	Flat Glass	40	16.4	0.93	17.3	0.056	0.01	0.066	34.5	662.3	5.2	0.01

*Equiv. = Equivalent

TABLE A-11

SUMMARY OF TOTAL ENERGY PURCHASED (2- AND 4-DIGIT SIC GROUPING)

SIC CODE	INDUSTRY GROUP	1971		1967		1962		1958		1954	
		RANK	TOTAL ENERGY (10^{15} Btu)	RANK	TOTAL ENERGY (10^{15} Btu)	RANK	TOTAL ENERGY (10^{15} Btu)	RANK	TOTAL ENERGY (10^{15} Btu)	RANK	TOTAL ENERGY (10^{15} Btu)
3312	Blast Furnaces & Steel Mills	1	1.68	1	1.665	1	1.324	1	1.25	1	5.228
2911	Petroleum Refining	2	1.67	2	1.444	2	1.191	4	0.953	5	0.648
32*	Stone, Clay & Glass Products	4	1.48	3	1.369	3	1.167	2	1.032	2	0.971
26*	Paper & Allied Products	3	1.59	4	1.3405	4	1.05	5	0.996	4	0.726
20*	Food & Kindred Products	5	1.266	5	1.073	6	0.938	6	0.879	3	0.8911
2819	Industrial Inorganic Chemicals	7	0.805	6	0.924	5	0.991	3	0.993	6	0.4381
2818	Industrial Organic Chemicals	6	1.116	7	0.889	7	0.5964	7	0.382	8	0.3019
3334	Primary Aluminum	8	0.592	8	0.592	8	0.397	9	0.274		NC
22*	Textile Mill Products	9	0.54	9	0.459	9	0.459	8	0.3119	7	0.330
2812	Alkalies & Chlorine	10	0.236	10	0.252	11	0.230	11	0.184	12	0.1183
3712	Motor Vehicles - Passenger Cars	15	0.156	11	0.159		NA		NA		NA
2821	Plastic Materials & Resins	11	0.201	12	0.154	14	0.099	14	0.095	15	0.073
3714	Motor Vehicles Parts & Acc.	12	0.187	13	0.1536	10	0.2417	10	0.213	10	0.1831
2815	Cyclic Intermediates	14	0.161	14	0.1427	12	0.1265	12	0.103	14	0.0805
3313	Electrometallurgical Products	16	0.136	15	0.1295	13	0.1206	15	0.085	16	0.066
3321	Gray Iron Foundries	18	0.132	16	0.1156	16	0.081	17	0.062	13	0.085
2813	Industrial Gases	17	0.133	17	0.1118	21	0.0511		NC		NC
3562	Ball & Roller Bearing		0.02	18	0.1081		NC		NC		NC
2824	Organic fibers, Noncellulosic	13	0.183	19	0.1058		NC		NC		NC
2823	Cellulosic Manmade Fibers		0.086	20	0.1022	15	0.0896	13	0.095		NC
3352	Aluminum Rolling & Drawing	21	0.122	21	0.0947	19	0.0601	21	0.042		NC
2421	Sawmills & Planing Mills	23	0.117	22	0.0859	18	0.0626	19	0.05	19	0.055
3011	Tires & Inner Tubes		0.109	23	0.0854	17	0.0767		NC	18	0.061
3561	Pumps & Compressors		0.023	24	0.0791		NC		NC		NC
3461	Metal Stampings		0.08	25	0.0700		NC		NC		NC

* 4 Digit SIC for 1971's 32, 26, 20, 22

Not Available

TABLE A-12

SUMMARY OF TOTAL ENERGY PURCHASED (2- AND 3-DIGIT SIC GROUPING)

SIC CODE	INDUSTRY GROUP	1971		1967		1962		1958		1954	
		RANK	TOTAL ENERGY (10^{15} Btu)	RANK	TOTAL ENERGY (10^{15} Btu)	RANK	TOTAL ENERGY (10^{15} Btu)	RANK	TOTAL ENERGY (10^{15} Btu)	RANK	TOTAL ENERGY (10^{15} Btu)
281	Industrial Chemicals	1	2.51	1	2.37	1	2.02	1	1.73	6	0.559
331	Blast Furnace & Steel Products	2	1.87	2	1.86	2	1.47	2	1.371	1	5.291
291	Petroleum Refining	3	1.68	3	1.44	3	1.19	4	0.952		NA
32*	Stone Clay & Glass Products	5	1.48	4	1.37	4	1.17	3	1.032	2	0.971
26*	Paper & Allied Products	4	1.59	5	1.34	5	1.05	5	0.896	3	0.726
20*	Food & Kindred Products	6	1.266	6	1.07	6	0.938	6	0.879	4	0.891
333	Primary Nonferrous Metals	7	0.792	7	0.764	7	0.601	7	0.414	7	0.436
22*	Textile Mill Products	9	0.54	8	0.459	8	0.350	8	0.312	8	0.330
282	Plastics Materials & Synthetics	8	0.548	9	0.427	9	0.282	9	0.24	5	0.568
371	Motor Vehicles and Equipment	10	0.363	10	0.323	10	0.268	10	0.217	9	0.189
335	Nonferrous Rolling & Drawing	12	0.23	11	0.198	11	0.145	11	0.124	14	0.0685
332	Iron & Steel Foundries	13	0.214	12	0.198	12	0.135	12	0.113	10	0.144
372	Aircraft and Parts	19	0.149	13	0.148	13	0.110	13	0.098	12	0.0919
289	Misc. Chemical Products	25	0.134	14	0.119	15	0.069	17	0.042	13	0.0819
339	Misc. Primary Metal Products	28	0.113	15	0.105	18	0.058	14	0.057	11	0.102
344	Fabricated Structural Metal	27	0.116	16	0.100	17	0.064	15	0.055	16	0.044
242	Sawmills & Planing Mills	26	0.126	17	0.093	16	0.067	16	0.054	15	0.0575
287	Agricultural Chemicals	31	0.103	18	0.079	28	0.037		NA		NA
353	Construction & Related Machinery	34	0.09	19	0.076	19	0.057	18	0.04		NA
307	Misc. Plastic Products	22	0.144	20	0.075	31	0.033	24	0.03		NA
367	Electronic Components & Acc.	39	0.085	21	0.07	26	0.038	28	0.022		NA
346	Metal Stampings	45	0.079	22	0.07	35	0.025	23	0.031	17	0.0434
295	Paving & Roofing Materials	50	0.069	23	0.069	27	0.0378	25	0.028		NA
356	General Industrial Machinery	43	0.082	24	0.068	20	0.051	20	0.033	19	0.0365
366	Communication Equipment	44	0.08	25	0.066	25	0.039	29	0.022	18	0.0396

* 3 Digit SIC for 32, 26, 22, 20 of 1971 not available.

TABLE A-13

SUMMARY OF TOTAL ENERGY PURCHASED (MAJOR 3-DIGIT SIC GROUPING)

SIC CODE	INDUSTRY GROUP	1971		1967		1962		1958		1954	
		RANK	TOTAL PURCHASED ENERGY (10^{15} Btu)	RANK	TOTAL PURCHASED ENERGY (10^{15} Btu)	RANK	TOTAL PURCHASED ENERGY (10^{15} Btu)	RANK	TOTAL PURCHASED ENERGY (10^{15} Btu)	RANK	TOTAL PURCHASED ENERGY (10^{15} Btu)
281	Industrial Chemicals	1	2.510	1	2.371	1	2.023	1	1.725	4	.5597
331	Blast Furnace & Basic Steel Products	2	1.870	2	1.859	2	1.472	2	1.371	1	5.2916
291	Petroleum Refining	3	1.680	3	1.444	3	1.191	3	0.952		
333	Primary Nonferrous Metals	4	0.792	4	0.764	4	0.601	6	0.414	5	.4355
262	Papermills, Except Building Paper	5	0.705	5	0.598	6	0.473	5	0.423		
324	Cement, Hydraulic	7	0.519	6	0.520	5	0.476	4	0.429		
263	Paperboard Mills	8	0.437	7	0.468	7	0.325	7	0.294		
282	Plastic Materials & Synthetics	6	0.548	8	0.427	8	0.282	8	0.240	3[1]	.5682
371	Motor Vehicles & Equipment	9	0.363	9	0.323	9	0.268	9	0.217	8	.1893
327	Concrete, Gypsum & Plaster Products	10	0.281	10	0.239	16	0.118	15	0.116		
322	Glass, Glassware, Pressed & Blown	11	0.246	11	0.206	11	0.165	12	0.139	6	.2631
335	Nonferrous Rolling & Drawing	12	0.230	12	0.198	13	0.145	13	0.124	18	.0685
332	Iron & Steel Foundries	13	0.214	13	0.198	14	0.135	16	0.113	10	.1436
325	Structural Clay Products	21	0.141	14	0.171	10	0.167	11	0.140	9	.1748
209	Misc. Food & Kindred Products	14	0.200	15	0.166	17	0.114	22	0.086	11	.1233
204	Grain Mill Products	15	0.181	16	0.157	15	0.123	17	0.102		
202	Dairy Products	20	0.148	17	0.154	12	0.145	10	0.158	7	.2051
372	Aircraft & Parts	19	0.149	18	0.148	19	0.110	18	0.098	15	.0919
201	Meat Products	16	0.176	19	0.139	18	0.114	14	0.117	12	.1220
203	Canned, Cured & Frozen Foods	18	0.165	20	0.136	23	0.098	23	0.076	20	.0608
329	Misc. Nonmetallic Mineral Products	17	0.165	21	0.125	20	0.105	24	0.075	19	.0621
289	Misc. Chemical Products	25	0.134	22	0.119	28	0.069	34	0.042	16	.0819
208	Beverages	23	0.144	23	0.115	21	0.102	21	0.084	14	.0953
206	Sugar	24	0.135	24	0.111	22	0.102	20	0.086	17	.0777
221	Weaving Mills, Cotton	37	0.087	25	0.107	24	0.098	19	0.095	28	.0329

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[1] Was "Organic Chemicals"

TABLE A-14

SUMMARY OF TOTAL ENERGY PURCHASED (MAJOR 4-DIGIT SIC GROUPING)

SIC CODE	INDUSTRY GROUP	1971		1967		1962		1958		1954	
		RANK	TOTAL PUR-CHASED ENERGY (10^{15} Btu)	RANK	TOTAL PUR-CHASED ENERGY (10^{15} Btu)	RANK	TOTAL PUR-CHASED ENERGY (10^{15} Btu)	RANK	TOTAL PUR-CHASED ENERGY (10^{15} Btu)	RANK	TOTAL PUR-CHASED ENERGY (10^{15} Btu)
3312	Blast Furnace & Steel Mills	1	1.6791	1	1.6659	1	1.3237	1	1.246	1	5.228
2911	Petroleum Refining	2	1.6786	2	1.4438	2	1.1905	3	0.953	2	0.6476
2819	Industrial Inorganic Chemicals, N.E.C.	4	0.8048	3	.9236	3	0.9913	2	0.993	4	0.4381
2818	Industrial Organic Chemicals, N.E.C.	3	1.116	4	.8889	4	0.5964	6	0.382		
2621	Papermills, Except Building Paper	5	0.705	5	.5985	6	0.4733	5	0.423		
3334	Primary Aluminum	6	0.592	6	.5920	7	0.3967	8	0.274	7	0.297
3241	Hydraulic Cement	7	0.519	7	.5196	5	0.4760	4	0.429	5	0.4035
2631	Paperboard Mills	8	0.508	8	.4676	8	0.3249	7	0.294		
2812	Alkalies & Chlorine	9	0.236	9	.2517	10	0.2298	10	0.184	12	0.1183
3712	Motor Vehicles	15[1]	0.156	10[2]	.1588	9[3]	0.2417	NC	NC	9[3]	0.1831
2821	Plastic Materials & Resins	10	0.201	11	.1540	14	0.0999	15	0.095	19[4]	0.0781
3716	Motor Vehicles, Parts & Accessories	11	0.187	12	.1536	NC	NC	7[3]	0.213	NC	NC
2815	Cyclic Intermediates & Crudes	14	0.1613	13	.1427	11	0.1263	11	0.103	17[5]	0.0805
3221	Glass Containers	13	0.166	14	.1347	13	0.1135	12	0.099	15	0.0864
3313	Electrometallurgical Products	18	0.136	15	.1295	12	0.1206	17	0.085	20	0.0659
3321	Gray Iron Foundries	20	0.132	16	.1157	18	0.0810	21	0.062	16	0.0852
2813	Industrial Gases	19	0.133	17	.1118	32	0.0511	NC	NC	NC	NC
3562	Ball & Roller Bearings	NC	NC	18	.1081	NC	NC	NC	NC	NC	NC
2211	Weaving Mills, Cotton	27	0.087	19	.1070	15	0.0981	13	0.096		
2824	Noncellulosic Organic Fibers	12	0.183	20	.1058	NC	NC	NC	NC	11[6]	
2823	Cellulosic Manmade Fibers	28	0.086	21	.1022	16	0.0896	14	0.095	NC	NC
3251	Brick & Structural Clay Tile	30	0.084	22	.1005	19	0.0804	18	0.084	12	0.103
2011	Meat Packing Plants	22	0.117	23	.0963	17	0.0894	16	0.094	13	0.1023
3352	Aluminum Rolling & Drawing	21	0.1221	24	.0947	26	0.0601	34	0.042	NC	NC
2611	Pulpmills	16	0.1456	25	.0937	22	0.0766	28	0.048	NC	NC

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[1] 3712 Motor Vehicles - Passenger Car Bodies

[2] 3711 Motor Vehicles

[3] 3717 Motor Vehicles

[4] 2823 Plastic Materials

[5] 2822 Intermediate & Organic Colors

[6] 2824 Synthetic Rubber

TABLE A-15

SUMMARY OF ENERGY/VALUE ADDED (2- AND 3-DIGIT SIC GROUPING)

SIC CODE	INDUSTRY GROUP	1971		1967		1962		1958		1954	
		RANK	ENERGY/VALUE ADDED (10^6 Btu/$)	RANK	ENERGY/VALUE ADDED (10^6 Btu/$)	RANK	ENERGY/VALUE ADDED (10^6 Btu/$)	RANK	ENERGY/VALUE ADDED (10^6 Btu/$)	RANK	ENERGY/VALUE ADDED (10^6 Btu/$)
333	Primary nonferrous metals	1	0.465	1	0.553	1	0.594	2	0.5911	2	0.7091
281	Industrial Chemicals	3	0.275	2	0.307	3	0.328	4	0.4050	4	0.4037
291	Petroleum Refining	2	0.365	3	0.304	2	0.379	3	0.4494		
286	Gum & Wood Chemicals	8	0.071	4	0.278	9	0.089	20	0.035		
331	Blast Furnace & Basic Steel Prods	4	0.16	5	0.183	4	0.171	5	0.1997	1	1.1128
32	Stone Clay & Glass Products		NA	6	0.164	5	0.1657	6	0.1866		NA
295	Paving & Roofing Materials	7	0.081	7	0.151	7	0.106	10	0.1045		
26	Paper & Allied Products		NA	8	0.137	6	0.142	7	0.157	6	0.1568
282	Plastics Materials & Synthetic	5	0.110	9	0.112	8	0.095	9	0.1264	5	0.1768
339	Misc. Primary Metal Products	6	0.091	10	0.093	10	0.0876	8	0.1291	8	0.0862
332	Iron and Steel Foundries	9	0.062	11	0.075	11	0.0687	11	0.0856	7	0.1073
289	Misc. Chemical Products	12	0.057	12	0.075	13	0.0669	14	0.0519	10	0.0725
241	Logging Camps & Contractors		NA	13	0.068	17	0.052	17	0.0395		
249	Misc. Wood Products		NA	14	0.063	21	0.0317	18	0.0376		
335	Nonferrous Rolling & Drawing	10	0.061	15	0.060	12	0.068	12	0.0717	9	0.0796
22	Textile Mill Products		NA	16	0.056	15	0.057	1	0.6421	3	0 6720
242	Sawmills & Planing Mills		NA	17	0.053	19	0.043	16	0.0400	12	0.0361
336	Nonferrous Foundries	14	0.041	18	0.045	18	0.052	13	0.0528		
347	Metal Services N.E.C.	13	0.045	19	0.045	16	0.0526	19	0.0351		
20	Food & Kindred Products		NA	20	0.0403	20	0.043	15	0.05012	11	0.0647
287	Agricultural Chemicals	11	0.059	21	0.029	14	0.0589		NA		
307	Misc. Plastic Products		NA	22	0.025	23	0.0201	22	0.0320		
371	Motor Vehicles & Equipment		NA	23	0.024	22	0.0209	21	0.0321	14	0.0296
346	Metal Stampings	15	0.018	24	0.023	25	0.0178	23	0.0300	13	0.0348
344	Fabricated Structural Metal Prods	16	0.016	25	0.020	24	0.0199	24	0.0186	15	0.0198

TABLE A-16

SUMMARY OF ENERGY/VALUE ADDED (MAJOR 3-DIGIT SIC GROUPING)

SIC CODE	INDUSTRY GROUP	1971		1967		1962		1958		1954	
		RANK	ENERGY/VALUE ADDED (10^6 Btu/$)	RANK	ENERGY/VALUE ADDED (10^6 Btu/$)	RANK	ENERGY/VALUE ADDED (10^6 Btu/$)	RANK	ENERGY/VALUE ADDED (10^6 Btu/$)	RANK	ENERGY/VALUE ADDED (10^6 Btu/$)
324	Cement, Hydraulic	3	0.449	1	0.640	1	0.606	1	0.5914		
333	Primary Nonferrous Metals	1	0.465	2	0.553	2	0.594	2	0.5911		
263	Paperboard Mills	7	0.255	3	0.310	7	0.274	5	0.350		
281	Industrial Chemicals	6	0.275	4	0.307	5	0.328	4	0.405	2	0.404
291	Petroleum Refining	4	0.365	5	0.304	4	0.379	3	0.449		
325	Structural Clay Products	9	0.191	6	0.280	6	0.302	6	0.285	1	0.411
286	Gum & Wood Chemicals	17	0.071	7	0.278	16	0.090	24	0.037		
266	Building Paper & Board Mills		NA	8	0.256	3	0.430	8	0.254		
262	Papermills, Except Building Paper	8	0.242	9	0.254	9	0.255	7	0.274		
261	Pulpmills	5	0.330	10	0.212	8	0.259	10	0.248	5	0.280
331	Blast Furnace & Basic Steel Products	2	0.465	11	0.183	11	0.171	11	0.200	6	1.113
206	Sugar		NA	12	0.170	10	0.172	9	0.254	4	0.310
295	Paving & Roofing Materials	15	0.081	13	0.151	14	0.106	17	0.105		
321	Flat Glass	12	0.099	14	0.142	25	0.021	12	0.178		
322	Glass, Glassware, Pressed & Blown	11	0.105	15	0.137	12	0.150	13	0.165	3	0.390
226	Textile Finishing, Except Wool	14	0.087	16	0.130	13	0.143	14	0.150		
282	Plastics Materials & Synthetics	10	0.110	17	0.112	15	0.098	16	0.126	7	0.177
327	Concrete, Gypsum & Plaster Products	16	0.073	18	0.097	23	0.056	20	0.0752		
339	Misc. Primary Metal Products	13	0.091	19	0.093	17	0.086	15	0.129	10	0.086
329	Misc. Nonmetallic Mineral Products	18	0.070	20	0.081	18	0.079	21	0.0751	9	0.094
332	Iron & Steel Foundries	20	0.062	21	0.075	20	0.069	19	0.086	8	0.107
289	Misc. Chemical Products	21	0.057	22	0.075	21	0.067	22	0.052		0.073
241	Logging Camps & Contracts		NA	23	0.068	24	0.052	23	0.040		
221	Weaving Mills, Cotton	19	0.069	24	0.066	19	0.078	18	0.088	11	0.073
326	Pottery & Related Products	22	0.049	25	0.065	22	0.065	25	0.033		

TABLE A-17

SUMMARY OF ENERGY/VALUE ADDED (2- AND 4-DIGIT SIC GROUPING)

SIC CODE	INDUSTRY GROUP	1971 RANK	1971 ENERGY/VALUE ADDED (10^6 Btu/$)	1967 RANK	1967 ENERGY/VALUE ADDED (10^6 Btu/$)	1962 RANK	1962 ENERGY/VALUE ADDED (10^6 Btu/$)	1958 RANK	1958 ENERGY/VALUE ADDED (10^6 Btu/$)	1954 RANK	1954 ENERGY/VALUE ADDED (10^6 Btu/$)
3334	Primary Aluminum	1	0.725	1	0.7293	2	0.7939	1	0.714	2	1.1241
3313	Electrometallurgical Products	2	0.626	2	0.6707	1	0.8289	6	0.475	6	0.574
2812	Alkalies & Chlorine	3	0.517	3	0.6005	3	0.5905	4	0.601	7	0.4713
3333	Primary Zinc			4	0.5624	4	0.5694	5	0.544	4	0.7304
2819	Industrial Inorganic Chemical N.E.C	4	0.395	5	0.4024	5	0.5210	2	0.676	8	0.4097
2911	Petroleum Refining	5	0.365	6	0.3843	6	0.3794	7	0.430	9	0.3606
2813	Industrial Gases	7	0.243	7	0.2790	11	0.1965				
2818	Industrial Organic Chemical N.E.C.	8	0.225	8	0.2486	9	0.2187	10	0.229	10	0.2578
2823	Cellulosic Manmade Fibers	6	0.339	9	0.2017	10	0.2177	9	0.243		
2815	Cyclic Intermediates & Crudes	9	0.176	10	0.1957	8	0.2218	8	0.276		
3312	Blast Furnaces & Steel Mills	10	0.163	11	0.1870	12	0.1719	11	0.206	1	1.1265
32	Stone Clay & Glass Products		NA	12	0.1642	13	0.1657	12	0.1866		NA
2822	Synthetic Rubber	11	0.162	13	0.1610					3	0.8005*
26	Paper & Allied Products		NA	14	0.1374	14	0.142	13	0.157	11	0.1568
3562	Ball & Roller Bearing			15	0.1290						
3352	Aluminum Rolling & Drawing	12	0.104	16	0.1010	7	0.2880	16	0.088		
3391	Iron and Steel Forgings			17	0.0964	15	0.1079	14	0.142	12	0.1525
2821	Plastic Materials & Resins	13	0.093	18	0.0942	16	0.0831	15	0.109	13	0.1252**
2824	Organic Fibers, Noncellulosic	14	0.090	19	0.0845						
3321	Gray Iron Foundries	15	0.059	20	0.0730	17	0.0693	17	0.077	14	0.1007
3561	Pumps & Compressors			21	0.0654						
22	Textile Mill Products		NA	22	0.0563	19	0.0572	3	0.6421	5	0.6720
2421	Sawmills & Planing Mills, Gen.	16	0.041	23	0.0552	20	0.0456	19	0.042	17	0.0362
3011	Tires & Inner Tubes			24	0.0469	18	0.0580			15	0.0725
20	Food & Kindred Products		NA	25	0.0403	21	0.043	18	0.05012	16	0.0647

* Code changed from 2824 to 2822

**Code changed from 2823 to 2821

TABLE A-18

SUMMARY OF ENERGY/VALUE ADDED (MAJOR 4-DIGIT SIC GROUPING)

SIC CODE	INDUSTRY GROUP	1971		1967		1962		1958		1954	
		RANK	ENERGY / VALUE ADDED (10^6 Btu/$)	RANK	ENERGY / VALUE ADDED (10^6 Btu/$)	RANK	ENERGY / VALUE ADDED (10^6 Btu/$)	RANK	ENERGY / VALUE ADDED (10^6 Btu/$)	RANK	ENERGY / VALUE ADDED (10^6 Btu/$)
3274	Lime	1	0.735	1	0.8230	NC	NC	2	0.693	NC	NC
3334	Primary Aluminum	2	0.725	2	0.7293	2	0.7939	1	0.714	2	1.1241
3313	Electrometallurgical Products	3	0.626	3	0.6707	1	0.8289	7	0.475	6	0.574
3241	Hydraulic Cement	6	0.449	4	0.6394	3	0.6059	5	0.592	4	0.7629
2812	Alkalies & Chlorine	4	0.517	5	0.6005	4	0.5905	4	0.601	9	0.4713
3333	Primary Zinc	NC	NC	6	0.5624	5	0.5694	6	0.544	5	0.7304
2819	Industrial Inorganic Chemicals, N.E.C.	7	0.395	7	0.4026	6	0.5210	3	0.676	11	0.4097
3251	Brick & Structural Clay Tile	11	-0.250	8	0.4004	9	0.3716	9	0.427	7	0.560
2631	Paperboard Mills	10	0.255	9	0.3100	11	0.2739	11	0.350	NC	NA
2911	Petroleum Refining	8	0.365	10	0.3043	8	0.3794	8	0.450	11	0.3406
2063	Beet Sugar	NA	NA	11	0.2904	10	0.2889	10	0.376	NC	NC
2611	Pulpmills	5	0.475	12	0.2808	12	0.2592	17	0.265	NC	NA
2813	Industrial Gases	12	0.263	13	0.2790	18	0.1965	NC	NC	NC	NC
2621	Papermills, Except Building Paper	13	0.262	14	0.2540	13	0.2548	15	0.274	NC	NA
2818	Industrial Organic Chemicals, N.E.C.	14	0.225	15	0.2486	16	0.2187	20	0.229	NC	NC
2823	Cellulosic Manmade Fibers	9	0.339	16	0.2017	17	0.2177	18	0.243		
2815	Cyclic Intermediates & Crudes	16	0.174	17	0.1957	15	0.2218	14	0.275	20	0.2216
3312	Blast Furnaces & Steel Mills	18	0.163	18	0.1870	21	0.1719	21	0.206	1	1.1265
2046	Wet Corn Milling	15	0.207	19	0.1810	19	0.1837	22	0.201		
2822	Synthetic Rubber	19	0.162	20	0.1610	NC	NC	NC	NC	NC	NC
3221	Glass Containers	20	0.119	21	0.1600	20	0.1802	29	0.122	13	0.2971
3211	Flat Glass	30	0.010	22	0.1416	23	0.1435	24	0.175		
3562	Ball & Roller Bearings	NC	NC	23	0.1290	NC	NC	NC	NC	NC	NC
3229	Pressed & Blown Glass, N.E.C.	25	0.085	24	0.1085	25	0.1137	28	0.131	24	0.1301
3352	Aluminum Rolling & Drawing	21	0.104	25	0.1010	27	0.0833	31	0.088		

TABLE A-19

SUMMARY OF ENERGY COST/VALUE ADDED (2- AND 3-DIGIT SIC GROUPING)

SIC CODE	INDUSTRY GROUP	1971		1967		1962		1958		1954	
		RANK	ENERGY COST / VALUE ADDED (c/$)	RANK	ENERGY COST / VALUE ADDED (c/$)	RANK	ENERGY COST / VALUE ADDED (c/$)	RANK	ENERGY COST / VALUE ADDED (c/$)	RANK	ENERGY COST / VALUE ADDED (c/$)
333	Primary Nonferrous Metals	2	18.0	1	17.655	1	17.51	1	18.95	3	18.30
281	Industrial Chemicals	4	12.1	2	10.841	2	11.6	2	14.04	2	22.71
331	Blast Furnace & Basic Steel Prods.	5	10.9	3	9.549	4	10.32	4	10.68	1	28.82
291	Petroleum Refining	3	12.8	4	8.796	3	10.78	3	11.32	5	7.11
286	Gum & Wood Chemicals	11	4.2	5	8.130	11	5.48	10	5.38		NC
295	Paving & Roofing Materials	9	5.2	6	7.700	7	6.86	8	6.75		NC
32	Stone Clay & Glass Products		NA	7	7.654	5	7.89	6	8.48		NC
332	Iron & Steel Foundries	7	6.0	8	6.313	8	6.66	7	7.57	4	7.22
241	Logging Camps & Contractors		NA	9	6.200	10	5.76	12	4.84		NC
339	Misc. Primary Metal Product	6	6.5	10	6.150	6	7.00	5	8.51	8	5.19
26	Paper & Allied Products		NA	11	5.912	9	6.20	9	6.71	6	6.73
242	Sawmills & Planing Mills		NA	12	4.750	15	4.30	13	4.83	11	3.59
347	Metal Services, N.E.C.	12	6.1	13	4.400	12	5.01	11	4.88		NC
282	Plastics Materials & Synthetics	8	5.8	14	4.333	17	3.77	15	4.54	7	5.39
249	Misc. Wood Products		NA	15	4.100	20	3.15	20	3.20		NC
335	Nonferrous Rolling & Drawing	10	4.6	16	3.910	13	4.53	14	4.57	9	5.11
336	Nonferrous Foundries	13	3.4	17	3.510	14	4.31	16	4.47		NC
22	Textile Mill Products		NA	18	3.489	18	3.62	17	4.16	10	4.14
289	Misc. Chemical Products	14	3.2	19	3.333	19	3.18	18	3.76	12	3.16
307	Misc. Plastic Products		NA	20	2.810	21	2.91	21	3.13		NC
20	Food & Kindred Products		NA	21	2.485	22	2.73	22	2.96	13	3.04
346	Metal Stamping	15	1.8	22	2.060	23	2.16	23	2.36	14	2.80
344	Fabricated Structural Metal Prod.	16	1.5	23	1.760	24	1.88	25	1.75	16	1.62
371	Motor Vehicles & Equipment		NA	24	1.640	25	1.47	24	2.15	15	1.96
287	Agricultural Chemicals	1	18.9	25	1.550	16	4.03	19	3.58		NC

TABLE A-20

SUMMARY OF ENERGY COST/VALUE ADDED (2- AND 4-DIGIT SIC GROUPING)

SIC CODE	INDUSTRY GROUP	1971		1967		1962		1958		1954	
		RANK	ENERGY COST / VALUE ADDED (¢/$)	RANK	ENERGY COST / VALUE ADDED (¢/$)	RANK	ENERGY COST / VALUE ADDED (¢/$)	RANK	ENERGY COST / VALUE ADDED (¢/$)	RANK	ENERGY COST / VALUE ADDED (¢/$)
3313	Electrometallurgical Prod.	1	29.8	1	26.139	1	33.13	5	17.07	6	18.91
2812	Alkalies & Chlorine	3	24.5	2	22.90	3	20.14	4	20.37	5	19.4
3334	Primary Aluminum	2	26.6	3	21.78	2	23.3	3	20.64	2	27.07
3333	Primary Zinc	NC	NC	4	19.163	5	19.03	1	27.23	4	19.88
2813	Industrial Gases	5	17.5	5	15.864	6	14.22		NC		NC
2819	Industrial Inorganic Chem. N.E.C.	4	19.3	6	14.80	4	19.19	2	24.58	3	24.61
3312	Blast Furnaces & Steel Mills	8	11.2	7	9.846	8	10.51	7	11.15	1	29.07
2821	Plastics Materials & Resins	14	5.6	8	9.61	18	3.98	17	4.69		NC
2911	Petroleum Refining	7	12.8	9	8.786	7	10.74	6	11.32	8	7.11
32	Stone Clay & Glass Products		NA	10	7.554	10	7.889	8	8.483		NA
2815	Cyclic Intermediates & Crudes	9	9.9	11	7.416	11	6.49	10	7.26		NC
2818	Industrial Organic Chem. N.E.C.	10	8.1	12	7.373	12	6.36	14	6.69	11	6.4
3391	Iron & Steel Forgings	NC	NC	13	6.713	9	7.94	9	8.38	7	7.9
3321	Gray Iron Foundries	13	6.0	14	6.655	17	4.76	11	7.18	9	6.8
2822	Synthetic Rubber	12	6.6	15	6.026		NC		NC	12	4.6
26	Paper & Allied Products		NA	16	5.912	13	6.203	13	6.705	10	6.728
3352	Aluminum Rolling & Drawing	11	6.6	17	5.753	15	5.38	15	5.65		NC
2823	Cellulosic Manmade Fibers	6	15.3	18	5.68	14	5.59	12	6.76	14	3.8
2421	Sawmills & Planing Mills, Gen.	16	2.0	19	4.947	16	4.91	16	5.02	15	3.64
22	Textile Mill Product		NA	20	3.489	19	3.618	18	4.142	13	4.136
2824	Organic Fiber, Noncellulosic	15	4.7	21	3.299		NC		NC		NC
20	Food & Kindred		NA	22	2.485	20	2.728	19	2.96	16	3.044
3011	Tires & Inner Tubes	NC	NC	23	2.232	21	2.69		NC	17	2.9
3461	Metal Stampings	17	1.8	24	2.059		NC		NC		NC
3714	Motor Vehicle Parts & Acc.		NA	25	1.922		NC		NC		NC

TABLE A-21

SUMMARY OF ENERGY COST/VALUE ADDED (MAJOR 3-DIGIT SIC GROUPING)

SIC CODE	INDUSTRY GROUP	1971		1967		1962		1958		1954	
		RANK	ENERGY COST / VALUE ADDED (c/$)	RANK	ENERGY COST / VALUE ADDED (c/$)	RANK	ENERGY COST / VALUE ADDED (c/$)	RANK	ENERGY COST / VALUE ADDED (c/$)	RANK	ENERGY COST / VALUE ADDED (c/$)
324	Cement, Hydraulic	1	21.0	1	23.452	1	21.89	1	22.8		
333	Primary Nonferrous Metals	3	18.8	2	17.655	3	17.53	2	18.95	3	18.39
325	Structural Clay Products	9	10.7	3	13.237	4	14.07	4	14.0	4	14.53
266	Building Paper and Board Mills	NC	NA	4	12.740	2	20.05	7	12.31		
263	Paperboard Mills	5	12.9	5	11.420	9	10.29	5	13.0		
261	Pulpmills	2	18.9	6	11.060	10	10.10	6	12.89	5	11.87
281	Industrial Chemicals	7	12.1	7	10.841	5	11.60	3	14.04	2	22.71
262	Papermills, Except Building Paper	4	12.9	8	10.525	7	10.63	9	10.76		
331	Blast Furnace & Basic Steel Products	8	10.9	9	9.549	8	10.32	10	10.68	1	28.82
291	Petroleum Refining	6	12.8	10	8.796	6	10.78	8	11.32		
286	Gum & Wood Chemicals	20	4.2	11	8.130	19	5.48	18	5.38		
295	Paving & Roofing Materials	16	5.2	12	7.700	13	6.86	17	6.75		
322	Glass, Glassware, Pressed & Blown	11	6.3	13	6.902	11	7.82	13	7.94	23	1.688
321	Flat Glass	17	5.2	14	6.780	15	6.47	16	7.21		
226	Textile Finishing, Except Wool	13	5.9	15	6.577	16	6.41	14	7.88		
332	Iron & Steel Foundries	12	6.0	16	6.313	14	6.66	15	7.57	7	7.22
206	Sugar	NC	NA	17	6.242	17	6.13	11	8.77	6	9.299
241	Logging Camps & Contractors	NC	NA	18	6.200	18	5.76	23	4.84		
339	Misc. Primary Metal Products	10	6.5	19	6.150	12	7.00	12	8.51	9	5.196
327	Concrete, Gypsum & Plaster Products	19	4.7	20	5.254	20	5.01	19	5.23		
329	Misc. Nonmetallic Mineral Products	20	4.6	21	4.811	22	4.70	21	4.95	12	4.519
242	Sawmill & Planing Mills	NC	NA	22	4.750	26	4.30	24	4.83	14	3.587
347	Metal Services, N.E.C.	21	4.1	23	4.400	21	5.01	22	4.88		
282	Plastic Materials & Synthetics	14	5.8	24	4.333	32	3.77	28	4.54	8	5.39
249	Miscellaneous Wood Products	NC	NA	25	4.100	33	3.15	NC	3.20		

TABLE A-22

SUMMARY OF ENERGY COST/VALUE ADDED (MAJOR 4-DIGIT SIC GROUPING)

SIC CODE	INDUSTRY GROUP	1971		1967		1962		1958		1954	
		RANK	ENERGY COST / VALUE ADDED (c/$)	RANK	ENERGY COST / VALUE ADDED (c/$)	RANK	ENERGY COST / VALUE ADDED (c/$)	RANK	ENERGY COST / VALUE ADDED (c/$)	RANK	ENERGY COST / VALUE ADDED (c/$)
3274	Lime	1	34.5	1	31.369	NC	NC	1	30.04	NC	NC
3313	Electrometallurgical Products	2	29.8	2	26.139	1	33.13	8	17.07	8	18.91
3241	Cement, Hydraulic	5	21.0	3	23.45	3	21.89	4	22.80	4	24.33
2812	Alkalies & Chlorine	4	24.5	4	22.90	5	20.14	6	20.37	7	19.4
3334	Primary Aluminum	3	26.6	5	21.78	2	23.3	5	20.04	2	27.02
3333	Primary Zinc	NC	NC	6	19.163	8	19.03	2	27.23	4	19.88
3251	Brick & Structural Clay Tile	10	13.6	7	17.801	4	20.18	7	19.42	5	19.50
2813	Industrial Gases	8	17.5	8	15.964	9	14.22	NC	NC	NC	NC
2621	Papermills, Except Building Papers	11	12.9	9	15.25	11	10.63	16	10.76	NC	NA
2819	Industrial Inorganic Chemicals, N.E.C.	6	19.3	10	14.80	7	19.19	3	24.58	3	24.6
2631	Paperboard Mills	12	12.9	11	11.42	13	10.29	10	13.00	NC	NA
2611	Pulpmills	7	18.9	12	11.058	14	10.14	12	12.89	NC	NA
2063	Beet Sugar	NC	NA	13	10.539	15	9.92	11	12.90		
3312	Blast Furnaces & Steel Mills	14	11.2	14	9.846	12	10.51	15	11.15	1	29.07
2821	Plastic Materials & Resins	23	5.6	15	9.61	31	3.98	33	4.69		
2911	Petroleum Refining	13	12.8	16	8.786	10	10.74	14	11.32	16	7.11
3221	Glass Containers	19	7.0	17	7.87	17	8.86	28	5.61	12	9.5
2815	Cyclic Intermediates & Crudes	15	9.9	18	7.416	21	6.49	19	7.26		
2818	Industrial Organic Chemicals, N.E.C.	18	8.1	19	7.373	24	6.36	24	6.69		
3211	Flat Glass	25	5.2	20	6.786	22	6.47	20	7.21		
2046	Wet Corn Milling	17	8.9	21	6.741	27	5.23	29	5.38	22	6.2
3391	Iron & Steel Forgings	NC	NC	22	6.713	18	7.94	17	8.38	14	7.9
3321	Grey Iron Foundries	22	6.0	23	6.655	29	4.76	21	7.18	19	6.8
2822	Synthetic Rubber	21	6.6	24	6.026	NC	NC	NC	NC	15	7.7
3352	Aluminum Rolling & Drawing	20	6.6	25	5.753	26	5.38	27	5.65		

TABLE A-23

UNIT FUEL AND ELECTRIC ENERGY COSTS FOR 40 INDUSTRY SECTORS (1971)

SIC CODE	INDUSTRY	RANK	¢/10^6 Btu	¢/kWh	Energy Cost/ Value Added (¢/$)	Total Purchased Fuel (10^9 kWh Equiv.)	Total Purchased Electric Energy (10^9 kWh)
2911	Petroleum Refining	1	28.6	0.77	12.8	422.3	22.5
3312	Blast Furnaces & Steel Mills	2	54.9	0.97	11.2	367.9	40.3
2818	Industrial Organic Chemical Nec.	3	29.6	0.68	8.1	266.3	19.7
2621	Paper Mills, Except Bldg. Paper	4	45.6	0.80	12.9	154.3	16.9
2819	Industrial Inorganic Chemicals	5	33.6	0.72	19.3	132.8	33.5
2631	Paperboard Mills	6	45.8	0.85	12.9	128.0	6.7
3241	Cement, Hydraulic	7	38.1	0.93	21.0	125.9	8.5
3334	Primary Aluminum	8	24.5	0.43	26.6	41.9	42.7
2812	Alkalies & Chlorine	9	41.0	0.59	24.5	40.9	9.1
2821	Plastic Materials & Resins	10	47.3	0.89	5.6	39.3	6.4
2824	Organic Fibers, Noncellulosic	11	43.9	0.78	4.7	38.6	4.8
3221	Glass Containers	12	50.7	0.93	7.0	38.2	3.6
2815	Cyclic Intermediates & Crudes	13	48.0	0.93	9.9	37.0	3.3
3714	Motor Vehicles Parts & Accessories	14	59.5	1.17	NA	27.8	8.8
3711	Motor Vehicles	15	63.7	1.14	NA	26.3	6.7
3321	Gray Iron Foundries	16	93.8	1.23	6.0	24.8	4.5
3274	Lime	17	42.8	1.11	34.5	26.4	0.6
2011	Packing Plants	18	48.4	1.22	NA	23.1	3.6
2611	Pulp Mills	19	31.1	0.66	18.9	23.8	2.5
3352	Aluminum Rolling & Drawing	20	51.8	0.85	6.6	21.1	4.8
3079	Misc. Plastic Products	21	55.9	1.23	NA	17.3	8.2
3273	Ready-Mixed Concrete	22	67.0	1.56	3.9	23.5	1.0
2063	Beet Sugar	23	40.4	1.28	NA	24.2	0.2
2421	Sawmills & Planing Mills, General	24	83.5	1.38	2.0	19.5	4.8
2823	Cellulosic Manmade Fibers	25	42.5	0.88	15.3	23.5	0.5
3313	Electrometallurgical Products	26	34.5	0.59	29.8	16.3	7.7
3251	Brick & Structural Clay Tile	27	46.5	1.40	13.6	22.5	0.7
2813	Industrial Gases	28	30.0	0.80	17.5	12.6	8.5
3331	Primary Copper	29	49.0	0.94	9.3	19.6	1.4
3229	Pressed & Blown Glass, Nec.	30	53.2	0.98	5.2	18.5	1.6
2822	Synthetic Rubber	31	31.0	0.71	6.6	17.3	1.9
2046	Wet Corn Milling	32	37.1	0.96	8.9	17.9	0.7
3211	Flat Glass	33	45.9	0.94	5.2	16.4	0.9
2042	Prepared Feeds for Animals & Fowls	34	49.3	1.23	NA	13.5	2.3
2816	Inorganic Pigments	35	50.3	0.97	9.5	14.5	1.2
2026	Fluid Milk	36	58.1	1.41	NA	12.9	2.8
2033	Canned Fruits and Vegetables	37	54.6	1.29	2.7	14.2	1.3
3461	Metal Stampings	38	64.4	1.32	1.8	11.6	3.8
3391	Iron & Steel Forgings	39	59.4	1.36	5.8	13.6	0.8
2211	Weaving Mills, Cotton	40	48.2	0.85	4.8	8.8	5.4

NOTES ON GRAPHS

Pictorial Representation of Selected Energy Data

In addition to examining the more traditional indicators such as total purchased energy use, energy cost/unit value added and energy use rate per unit value added, we examined the 1971 Census of Manufactures data to determine whether a correlation could be obtained among selected factors within the 4-digit SIC industries. Among the factors examined were:

- Purchased electric energy unit cost and total purchased electricity.
- Unit electric energy cost in total energy cost per dollar of value added.
- Purchased fuel energy unit cost and total purchased fuel.
- Purchased fuel unit costs and total energy cost per dollar of value added.

These data are shown on the following graphs.

There are certain industry characteristics which are reflected in those industries which are furthest from the largest concentration of the data population. For example, although the lime industry (SIC 3274) obtains its fuel and electric energy at unit prices competitive with the rest of industry, for the low value added during manufacture the unit costs are high. This reflects the high energy usage required in the production of lime as well as the nature of the industry, i.e., location, size and so on. Similarly, the aluminum industry (SIC 3334) obtains electricity at low unit costs because of the large amount of hydroelectric power; however, it also obtains purchased fuels at attractive unit costs compared with other industries. Similar observations might be made among the relative position of other industries; however, these attempted correlations seemed of little value in obtaining a better quantitative understanding of energy relationships among industries and they are incorporated here for future reference purposes only.

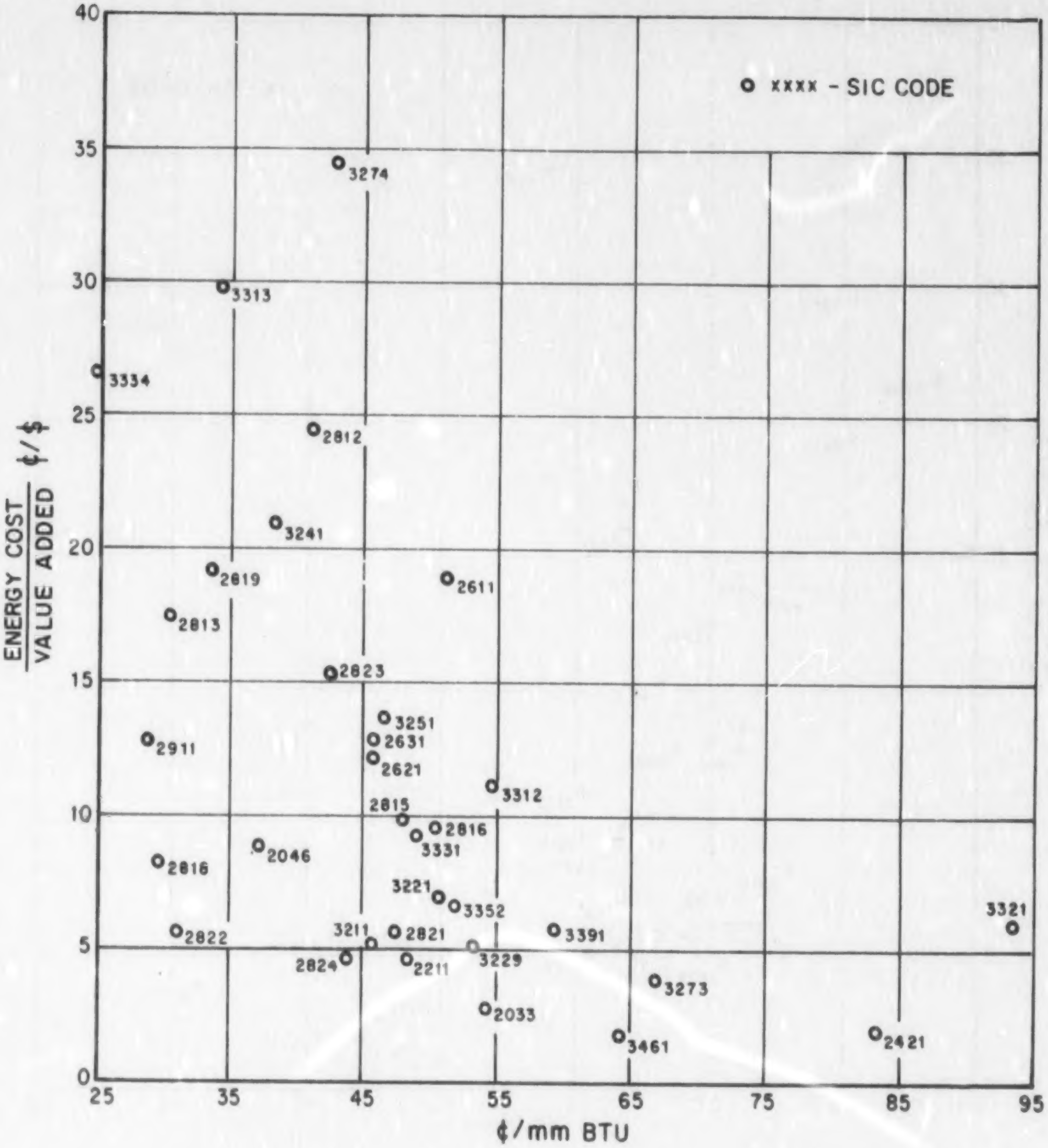

Figure A-1. Purchased Fuel Unit Costs Versus Total Energy Cost Per Dollar Value Added (1971)

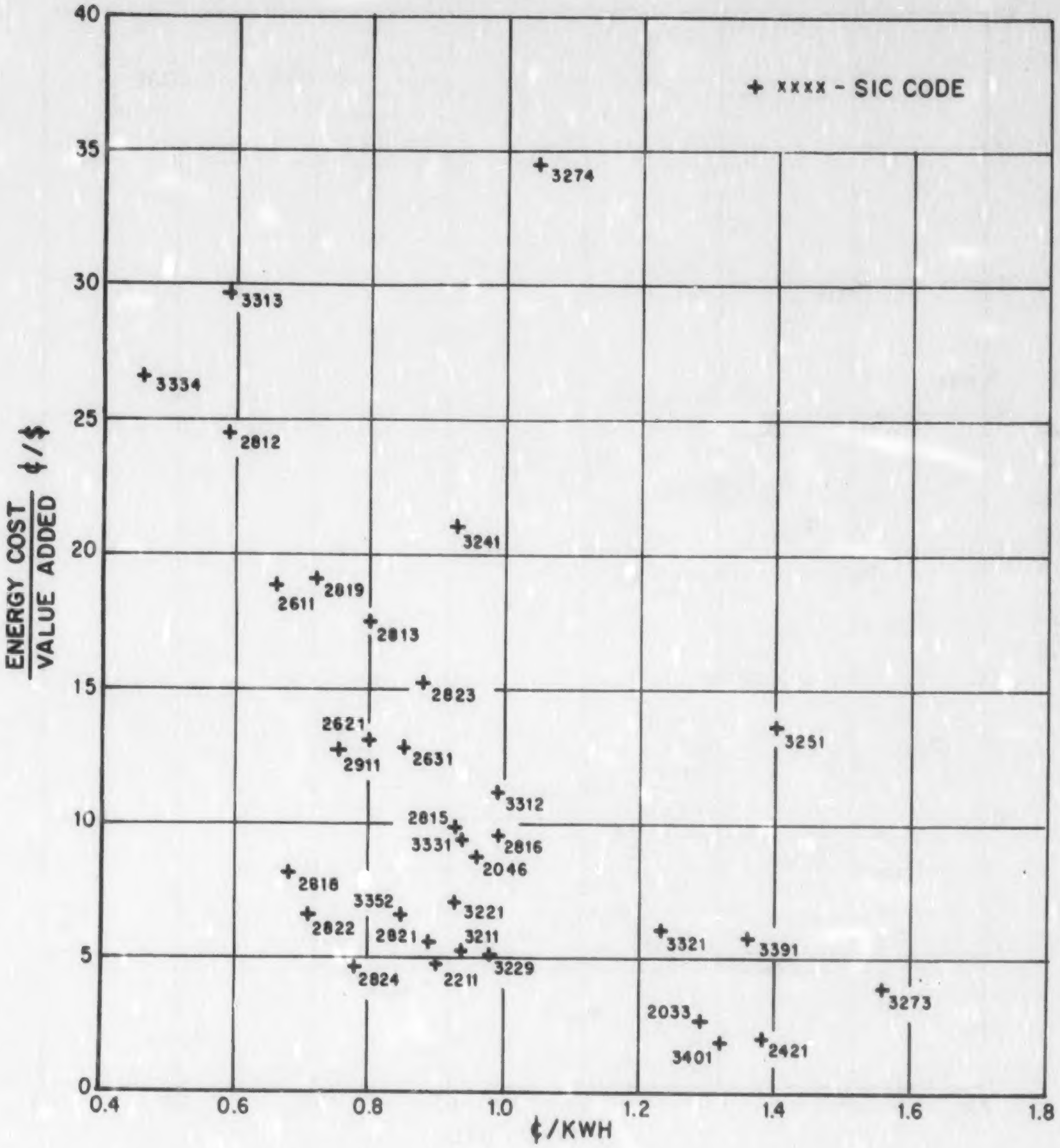

Figure A-2. Unit Electric Energy Cost Versus Total Energy Cost Per Dollar Value Added (1971)

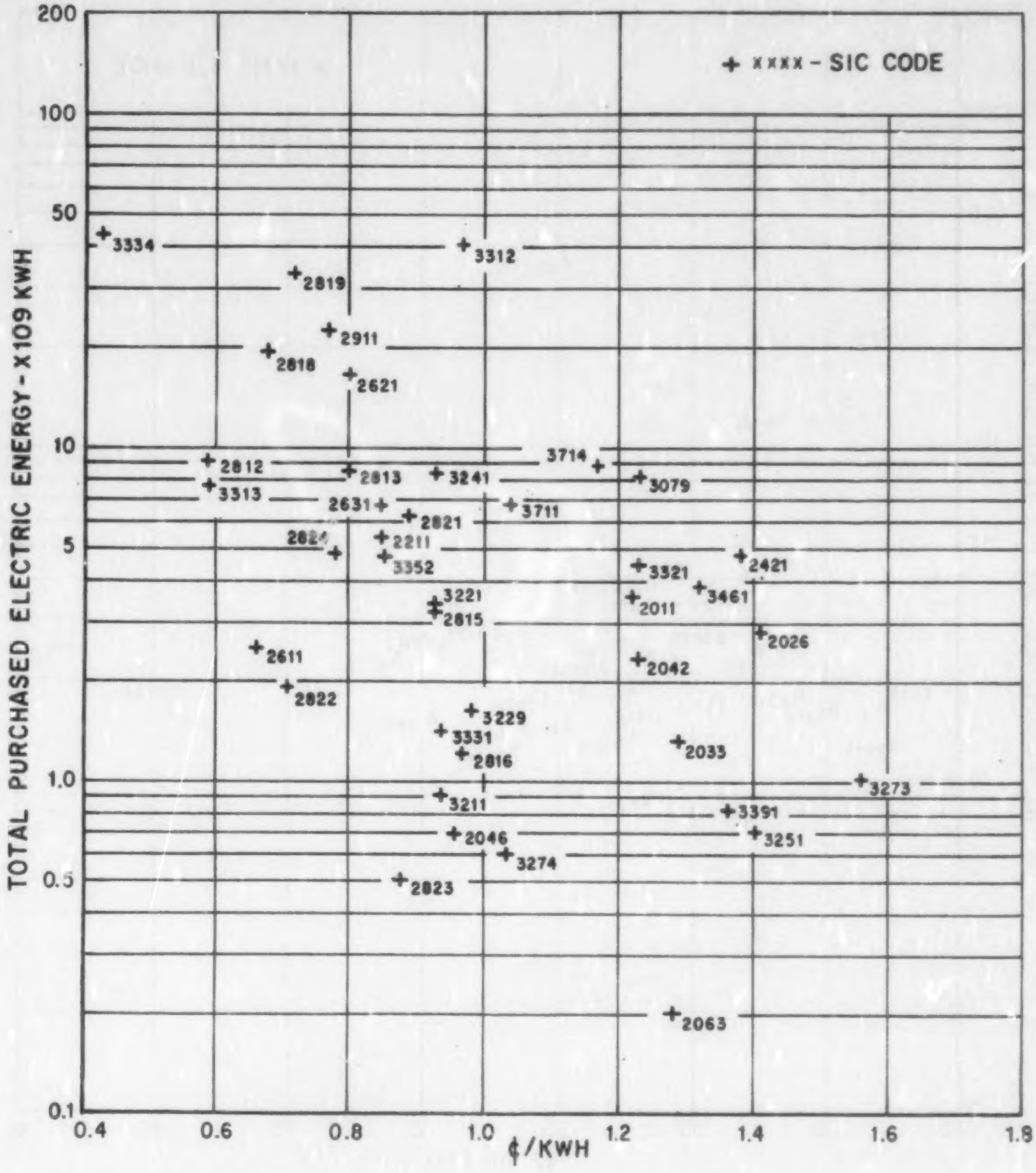

Figure A-3. Purchased Electric Energy Unit Costs Versus Total Purchased Electricity (1971)

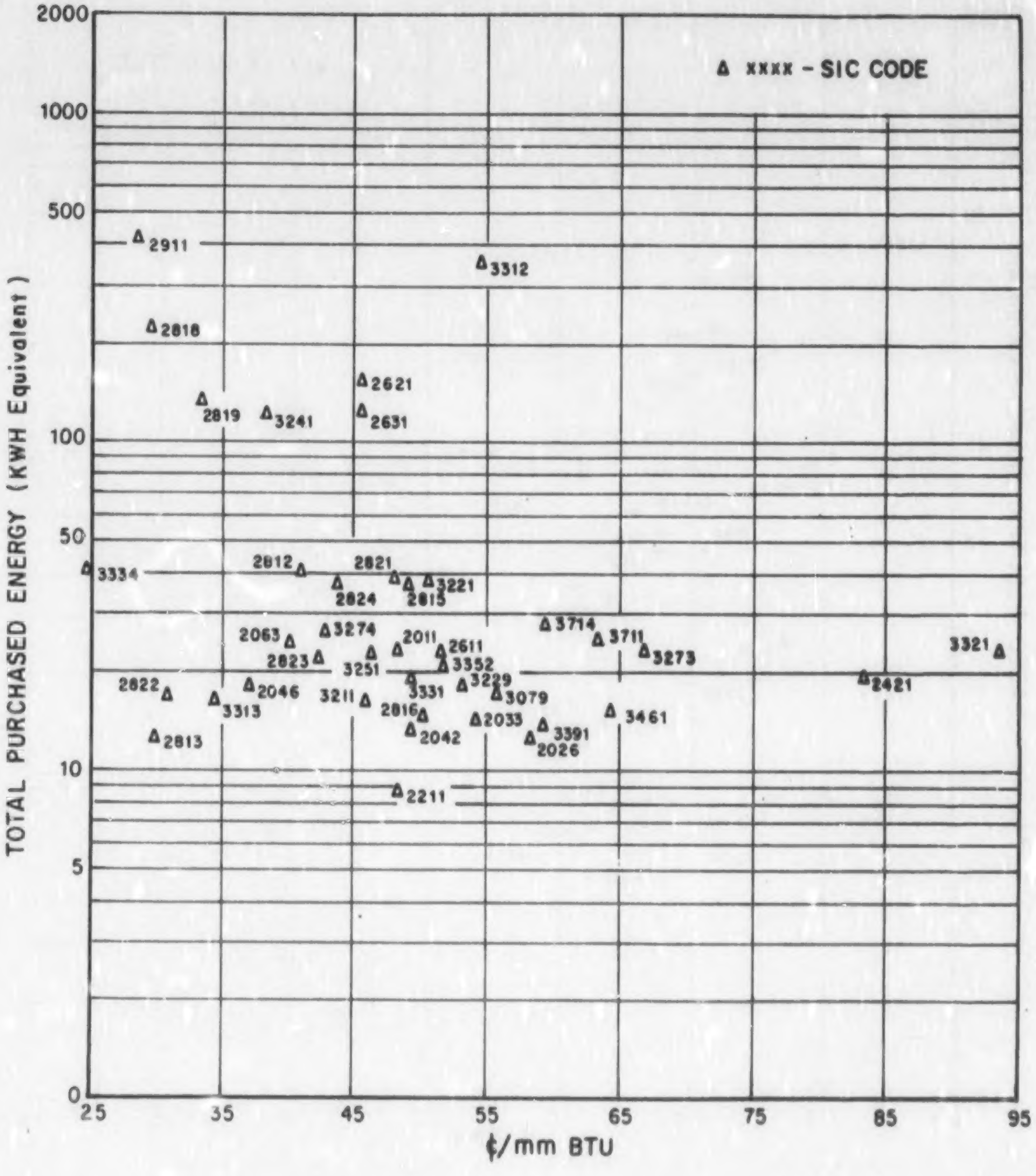

Figure A-4. Purchased Fuel Unit Cost Versus Total Purchased Fuel (1971)

APPENDIX B

INDUSTRY PERSPECTIVES

APPENDIX B

INDUSTRY PERSPECTIVES

1. IRON AND STEEL (BLAST FURNACES) (SIC 3312)

a. Technological Developments

As a result of technological advances, the world steel industry has been experiencing changes at each major step of the steel-producing operation. Not only has there been a continuous growth in steel capacity, but improvements in metallurgical processes, product properties, and production economics have been especially noticeable over the past decade and have led to major changes in the planning and operation of steel complexes.

Since World War II, advances in iron ore beneficiation have made possible the exploitation of lower grades of ore. The resulting agglomerated, high iron content product, coupled with faster blowing rates used with high top pressure, have tremendously increased blast furnace production while at the same time achieving lower coke rates. Coke oven throughputs, which remained static for years, are now becoming larger and, with technological advances, a wider variety of coals can be blended to make quality metallurgical coke. In new shops the older, open hearth and Bessemer (or Thomas) technologies have been supplanted by oxygen steelmaking furnaces which are becoming ever larger. Oxygen steelmaking economics have been reinforced by the ability of steelmakers to obtain large volumes of low-cost oxygen. With significant quantities of local scrap available in many locations, along with direct reduction of iron ore, steelmaking with electric furnaces has also been growing quite rapidly. Continuous casting of billets - and more recently slabs - has gained widespread acceptance in new mills over conventional ingot casting, and hot-strip mills seem to be growing continuously larger.

b. The Industry

The United States is the world's largest producer of raw steel, accounting for about 151 million tons in 1973 and a somewhat comparable production in 1974. Total net shipments in 1973 were 111.5 million tons and total revenues for firms accounting for nearly 92% of the nation's raw steel output amounted to about $29 billion. In that year, the domestic steel industry operated plants with a cumulative effective raw steel capacity of about 160 million annual tons. We believe that domestic steel demand will experience continued steady growth through 1980, because of the need to expand, rebuild, and modernize much of the U.S. economic infrastructure, including transportation, power generation, extraction of energy resources, communications, and sanitation. Assuming that U.S. steel requirements will continue to grow at about 2-3% per year, and that the U.S. steel industry continues to supply about 85%

of this demand, annual raw steel production should be about 175 million tons by 1980. Shipments would be about 135-140 million tons, and raw steel capacity would be about 185 million annual tons.

Virturally all U.S. raw steel production is derived via three process routes.

- coke oven-blast furnace-oxygen converter
- coke oven-blast furnace-open hearth
- scrap-(reduced product)-electric arc furnace

Raw steel so produced is then rolled to final shapes (bars, sheet, etc.) in a steelfinishing (rolling mill) operation.

The relative contributions of the different process routes to the national aggregate steel output have been changing since the early 1960's. Prior to this period, the open-hearth furnace was the dominant steelmaking unit. It achieved its alltime peak in 1964 when it accounted for over 77% of the 27 million tons of raw steel made in that year. The open-hearth has since declined in importance; no new furnaces are being built and none have been built for several years. Accordingly, the open-hearth accounted for only about 35.5 million tons in 1974 (less than 25% of total) and active units were generally operated at less than 90% of their real capacity. Total operating annual capacity for open-hearths is now less than 40 million tons of raw steel, and at least a quarter of this capacity is slated for replacement over the next two to three years. Much of the remainder will probably be operated only sporadically when steel demand is extraordinarily strong. In any case, we expect that by 1985, the open-hearth process will no longer be a significant factor in U.S. steel production.

The decline and eventual death of the open-hearth process has been dictated largely by the fact that the two other competing steelmaking processes - oxygen converter and electric arc furnace - have definite cost and operating advantages. For instance, the quality of the steel from the oxygen converter is similar to that from an open-hearth, but it is produced about 10 times faster (in 40 minutes instead of 6-7 hours for a 300-ton heat). Furthermore, because of developments in the past decade oxygen converter heats can be tapped on a predictable, periodic basis.

In 1974, oxygen converters--basic oxygen (BOF) and bottom-blown (Q-BOP)--were responsible for about 56% of U.S. raw steel production, up from 55.2% in 1973. Total installed capacity in 1974 was 87.81 million annual tons, an increase of 4.1 million tons over the prior year. Most of the operating capacity during 1974 came on-stream in the 1963-70 period which saw the installation of an average of 7.2 million tons of new capacity per year. The rate of increase has since declined substantially, as the rate of open-hearth replacement has been slowed. Future growth in oxygen steelmaking capacity will still be tied in part to the obsolence of the open-hearth and in part to actual increases in total industry capacity. On these bases, we expect its share of domestic raw steel production to equal about 67% in 1980 and about 75% in 1985. These would represent steel outputs of about 121 million and 150 million tons, respectively.

The electric arc furnace process, which has now established its viability as a significant supplier of stainless/specialty as well as plain carbon steels, has also witnessed a surge in capacity over the past decade. In 1974, it contributed about 20% of domestic raw steel output, and we expect it to capture as much as 40 million tons (or 22% of projected crude steel production) in 1980, rising to about 50 million tons (25% of production) by 1985. The pattern of capacity growth in the recent past as well as the anticipated continued growth are spurred on by a number of favorable technological, market, and economic considerations, principal among which are:

- the decline of the open-hearth process and the concurrent growth in oxygen steelmaking, both developments making more scrap readily available at economically attractive prices;
- the development of high-power arc furnace technology;
- the establishment of the economic viability of the "mini-mill" concept of relatively low-investment small-volume steelmaking devoted to serving the needs for simple fabricated products in a restricted market area; and
- the commercialization of iron ore direct reduction processes as a source of a high-quality substitute for scrap in the electric furnace.

c. Energy Utilization

In 1973 the U.S. basic steel industry consumed the equivalent of about four quadrillion Btu of energy, or 5.3% of the national total. Approximately 36 million Btu are required to make a ton of steel. The actual amount varies with the specified product and the age and efficiency of the equipment employed, with the older and less efficient plants requiring more energy and non-integrated plants much less. Table B-1 shows the estimated magnitudes of the energy used by source in 1973.

The industry historically has derived over 60% of its energy from coal, the principal secondary energy obtained therefrom being coke for the processing and smelting of iron ores. (It should be noted that the fuel values of auxiliary fuels arising from coke production and use--coke oven gas, tar, oil, and blast furnace gas--are included in the coal data.) Natural gas is the second most important fuel in terms of quantity used, followed in turn (in 1973) by fuel oil and electricity.

TABLE B-1

STEEL INDUSTRY ENERGY USE (1973)

Energy Source	Amount	% of Total (Btu Basis)
Coal	90.4×10^6 tons	64.5
Fuel Oil	2000×10^6 gal	8.4
Natural Gas	725×10^9 cu ft	20.6
Purchased Power	43.5×10^9 kWh	4.2
Other	94×10^{12} Btu	2.6

Raw Steel Production = About 151×10^6 tons

In analyzing energy utilization by form in the steel industry, it should be borne in mind that while steel plant facilities are generally designed with alternative fuel capabilities, certain steel processing applications, such as soaking pits, reheating furnaces, annealing, heat treating and coating lines, currently have no practical alternative to oil and gas as fuels. Further, many plants have taken advantage of the benefits of natural gas or oil to increase the production of such units as blast furnaces, open-hearths, and basic oxygen furnaces. Use of natural gas and oil in some of these applications could be eliminated, at the expense of time, money, and lost production. Thus, although the steel industry has provided for alternative fuels in many applications, much of this flexibility is presently an interchangeability between oil and gas. Little actual flexibility currently exists to convert large users from oil or gas to coal or electricity.

In view of these considerations, we believe that if in the near-term the steel industry is severely restricted in its consumption of both gas and oil, the consequence would be a reduction in domestic steel production. The longer term response would be pointed toward increased use of coal or energy derived from coal. The large programs required to move in this direction would probably include the development of new raw materials operations, an even more accelerated phasing out of open-hearth steelmaking, and the electrification of heating operations.

d. Environmental Problems

All major steel mill operations produce atmospheric emissions, wastewater effluents and solid wastes, although the quantities and characteristics from each source vary greatly. A medium-sized mill may discharge 100 million gallons of water/day while a single blast furnace may use air at the rate of more than 100,000 scfm and produce slag in excess of 1,000 ton/day. It is most constructive to review pollution problems in the iron and steel industry in terms of individual process operations.

The principal air pollution problems from byproduct coke ovens are sulfur dioxide from combustion of coke oven gas, emissions from ovens during charging and pushing and from door and lid leaks, and emissions from wastewater quenching of incandescent coke. State-of-the-art abatement measures include removing hydrogen sulfide from the gas, oven lid and door maintenance, baffling quench towers, and regulating coking times. The principal water pollution potentials in the byproduct coke plant are in ammonia still wastes and light oil decanter wastes which contain phenols, ammonia, cyanides, chlorides, and sulfur compounds. Abatement measures include biological treatment, chemical oxidation, and carbon adsorption.

Blast furnaces (as well as sinter plants) can produce particulate emissions in the off-gases from handling blast furnace burden materials, and from opening blast furnace pressure release valves due to slips. Hydrogen sulfide and some sulfur dioxide may be generated in slag quenching. Venturi scrubbers or electrostatic precipitators are used to clean blast furnace gas. As for water pollution problems in blast furnace plants, these result primarily from gas cleaning with wet washers. The wastewater contains suspended solids, cyanides, phenols, and ammonia. The major solid waste problem arises when more slag is produced than can be sold for road building. The solids recovered from blast furnace gas, either wet or dry, or from the sinter plant, are customarily reused as blast furnace burden.

The primary air pollution potentials of the steelmaking processes (oxygen converter, open-hearth, and electric arc furnace) are represented by the fumes generated from the furnaces themselves and during molten metal transfer operations. Control facilities on oxygen converters and open-hearth furnaces are generally either venturi scrubbers or electrostatic precipitators, while many newer electric arc furnaces employ bag houses. Water pollution problems in steelmaking result from wet gas-cleaning methods and consist primarily of suspended solids.

In steel rolling and finishing, the major air pollution source is hot scarfing. Airborne particles generated in this process are extremely fine and difficult to remove. The most important water pollution potentials are suspended particles of waterborne scale, lubricating oils, spent pickle liquor, and pickling rinse water. Most of the scale and oil is recovered in scale pits, and spent pickle liquor and rinse waters are often neutralized with lime.

e. Process Alternatives

Process alternatives that could be considered include:

- Conversion of the steelmaking process from the open-hearth to the basic oxygen furnace. This change is already occurring, the industry having shifted from practically no BOF production in 1957 to about 55% of total steel production in 1973. The trend is expected to continue until conversion is completed. The BOF offers a more facile adaptability to pollution control, and the control technology itself offers an energy source (low heating value CO-rich gas). In addition, the fuel consumption of the open-hearth is reduced. The shift means however, that energy must be expended in the production of the oxygen for the BOF and for melting (probably in electric furnaces) the scrap which is normally charged to the open-hearth but cannot be accommodated by the BOF. Appropriate use of the CO-rich gas fuel could compensate partly or wholly for these secondary energy demands, such as by fueling an air separation plant or generating on-site electricity.

- Substitution of Metallurgical Coke by Formed Coke. The development of formed-coke technology is already advanced both in the manufacturing process and in utilization. Formed-coke manufacturing technology promises easier accommodation to pollution control and a reduction in reliance on limited reserves of metallurgical coal. This latter advantage is compensated for by the need in the iron and steel plant for byproduct coke-oven gas which is not produced in formed-coke manufacturing processes. A substitute energy source would be needed. Dry quenching may offer an alternative for metallurgical coke manufacture to recover additional energy with implications for the reduction of pollution from the quench tower. Preheating of the coal blend may widen the range of accepted coals and reduce emissions because of the closed system and pipeline charging.

- Integrated Production of Steel by Direct Reduction and Electric Furnace Melting. This is the so-called "mini-mill" approach. The need for a metallurgical coal is avoided as are the attendant pollution problems. Fugutive emissions can be reduced by the closed-in nature of much of the equipment. Energy consumption per unit of production may be higher within the plant but this may be partially or fully compensated for by better locations relative to markets and a reduction of energy consumption in transportation. Increasing use of direct-reduced iron units could force the recycling of a cleaner scrap and reduce some of the electric-furnace emissions.

- Coke-Rate Improvement in the Blast Furnace. Coke-rate reduction reflects on reduced emission control investment in the byproduct coke-oven plant. Coke rates have historically improved mostly through more intensive physical preparation of the burden, rise in blast temperature, and injection of alternative fuels in the tuyeres. Production rates of iron can increase for a given furnace with reduced coke rate, thereby reducing the emissions per unit of production. Further improvement may come from oxygen enrichment of the blast and charging direct reduced iron units with the burden.

- Introduction of Submerged Oxygen Injection Steelmaking. This approach offers the advantages of reusing the buildings housing obsolete open-hearth furnaces, and conservation of oxygen and lime. Emissions may be reduced in comparison with top oxygen blowing. This process alternative can become significant in the short term.

- Development of Systems for Recovering Sensible Heat. Problems exist because of the intermittent nature of the processing and the high capital costs involved. This alternative may become significant in the middle term.
- Development of Continuous Steelmaking from Ironmaking to Steel Casting. As with any continuous process, gas cleaning and heat conservation could become more efficient through the operation of steady state control systems. This process alternative probably would become significant in the long term.
- Process alternatives in the idea stage would require perhaps a 20-year period for development before acceptance and commercial use. Included here is the use of energy from a high-temperature nuclear reactor to supply the energy for the direct reduction of the iron ore as well as to supply electricity for the steel works. It would appear that a significant depletion of fossil energy reserves needs to occur before such a route would become attractive. While several other processes can be considered (e.g., spray steelmaking, electric melting, fuel-oxygen-scrap (FOS) process) we believe they are of lesser significance for the U.S. industry.

2. PULP AND PAPER (SIC 262, 263, 261, 266)

a. SIC Categories Included in the Analysis

With a 1973 output valued at $30 billion, the U.S. pulp and paperboard industry, together with its allied industries, ranks eleventh among U.S. manufacturing industries. In 1972, the combined sectors of this industry used about 2,300 trillion Btu, thus ranking fourth in the country as a consumer of fuel and power and first as a manufacturing consumer of fuel oil. The industry includes about 6,000 individual plants in 49 states and employs about 720,000 people.

More specific to the aims of this study are the energy consumption and effluent control practices of the prime paper and paperboard manufacturing processes. The inclusion of the secondary industry--i.e., the conversion of paper and paperboard into corrugated boxes, stationery, cups, and other retail products--is not relevant to the aims of the study because: (a) energy consumption in these segments of the industry is low compared to that of the prime manufacturing processes and (b) the prime pollution problem facing these secondary manufacturing operations is solid waste disposal not water or air pollution. Accordingly, for purposes of this analysis we have included the four SIC categories--262, 263, 261, and 266--which comprise the manufacturing operations for the conversion of cellulosic fiber (pulpwood, "market" pulp or waste paper) to paper and paperboard products at the end of the paper machine. We have excluded the numerous converting operations (SIC 264 and 265) which are not major users of energy or faced with major air or water pollution problems. Table B-2 summarizes the purchased energy consumption of the SIC categories included in this analysis.

TABLE B-2

ENERGY PURCHASES FOR THE SIC CATEGORIES INCLUDED IN PULP AND PAPER INDUSTRY SECTOR ANALYSIS*
(Basis: 1971 Data)

SIC	INDUSTRY GROUPS	TOTAL PURCHASED ENERGY 10^3 tons	PURCHASED FUEL 10^{12} Btu/yr	PURCHASED POWER 10^9 kWh/yr	Equivalent** 10^{12} Btu/yr
262	Paper mills except bldg paper	697	527	17.0	170
263	Paper board mills	504	437	6.7	67
261	Pulp mills	106	81	2.5	25
266	Bldg. paper and board mills	56	40	1.6	16
	TOTAL	1363	1085	27.8	278

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* Does not include converting plants in SIC categories 264 and 265.

** Converted from kWh to Btu on the basis of 10,000 Btu/kWh, i.e., condensing power.

Table B-3 shows a reduction in purchased energy anticipated by the industry between 1971 and 1976, even though there is an estimated increase in production of some 12 million tons of paper and paperbaord products. Note also that while some of this reduction constitutes actual energy savings, much of it can be attributed to fuel switching, i.e., to more extensive use of the residue fuels (bark and "spent liquor") which are available to integrated pulp and paperboard plants. Because of the high cost of alternative fossil fuel, recovery of these residue fuel resources has become economically more attractive.

b. Energy Usage Patterns of Various Sectors

The industry uses various manufacturing processes, sometimes to make the same product, sometimes to make uniquely different products. For example, bleached kraft and sulfite pulp often are used interchangeably in the manufacture of the same product, while groundwood pulp is used to make dissimilar products. The energy requirements and the pollution control problems associated with each of these major product/process categories are quite dissimilar. Hence, an analysis of the potential impact of energy conservation measures upon effluent control must include the evaluation of each major process used in the industry. Table B-4 indicates annual production via each major process and the respective energy intensiveness of each. The table provides a convenient tool by which to assess the relative importance ot each process from an energy usage point of view. For example, the annual production of groundwood pulp is comparatively small, but the process ranks high in purchased energy requirements.

TABLE B-3

PROJECTED PURCHASED ENERGY CONSUMPTION
(Basis: Energy equivalents of fuel requirements)

Year	1971				1976				Change from 1971-1976	
Industry Production (10^6 tons)	55.1				67.1				Increase 12.0	
	Consumption				Consumption				Consumption	
Energy Source	10^{12} Btu		% of Total		10^{12} Btu		% of Total		10^{12} Btu	(%)
FOSSIL FUEL		1,321.4		55.3		1,217.7		47.5	- 103.7	-7.8
Coal	312.3		13.1		256.1		10.0			
Residue Fuel (#5,6)	412.4		17.3		506.9		19.8			
Distillate Fuel (#2)	27.7		1.2		49.4		1.9			
Liquid Propane Gas	0.3		Neg		2.4		Neg			
Gas	568.7		23.8		402.9		15.7			
RESIDUE FUEL		790.2		33.1		984.7		38.4	+ 194.5	- 24.6
Hogged Wood	9.6		4.0		68.7		2.6			
Bark	113.6		4.8		123.9		4.8			
Spent Liquor	667.0		27.9		791.1		30.9			
Other	NA		NA		1.0		Neg			
PURCHASED ENERGY		276.0		11.6		360.4		14.4	+ 84.4	+ 30.1
Electricity**	276		11.6		352.0		13.7			
Steam	NA				18.4		0.7			
TOTAL		2,387.6				2,562.8				

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* Includes SIC categories 264 and 265, as well as 261, 262, 263 and 266.

** Converted from the reported kWh to Btu on the basis of 10,000 Btu/kWh.

Source: American Paper Industry "Patterns of Fuel and Energy Consumption in the U.S. Pulp and Paper Industry" report March 1974 by J.M. Duke.

TABLE B-4

SUMMARY OF ENERGY USAGE IN THE PULP AND PAPER INDUSTRY BY MAJOR PULPING PROCESSES
(Basis: 1973 Production)

Energy Consumption - Annual Total (10^9 Btu)

	Production 10^3 tons per year	Total Energy requirement
I. WOOD PULP		
A. Integrated to Paper/Paperboard Making:(a)		
Kraft	29,201	N.A
Bleached	8,892	188.2
Unbleached	18,264	205.7
Semi-Bleached	2,045	33.2
Groundwood	4,532	57.7
Semi-Chemical	4,171	38.0
Sulfite	1,575	12.6
Defibrated/Exploded	3,485	26.1
B. Market Pulp:	5,345	N.A
Kraft	3,250	N.A
Bleached & Semi-Bleached	3,102	78.1
Unbleached	148	2.3
Sulfite	505	6.1
Dissolving	1,590	55.2
II. RECYCLED FIBER(a)		
A. Deinking	2,199(b)	26.6
B. Non-deinking		
Corrugated Containers	5,292	21.2
News	1,956	5.9
Mixed	3,371	10.1
P/S	1,500	4.5

(a) Does not include drying
(b) Includes 1/2 million tons of news

c. Example of Changes in Industrial Practices that will have an Impact Upon Energy Usage and Pollution Abatement Regulations

The following is a brief description of five examples of significant emerging technology in the virgin fiber pulping, chemical recovery, and bleaching processes. The intent is to identify "process changes" that will result in energy consumption changes and that may affect air and water pollution levels.

(1) Diffusion Washing and Bleaching

In the conventional system, pulp manufactured via either the kraft or sulfite pulping process is washed by diluting to low consistency (i.e., 1% solids or less) and then thickening to about 15% solids on a vacuum washer. Brown stock from a kraft pulp mill is typically put over three to four countercurrent washers with the stock being diluted and thickened in sequential steps.

Similarly, in a bleach plant, the pulp is treated with bleaching chemicals at 12% to 15% solids content or higher and then washed between each stage by diluting to low consistency and thickening on a vacuum washer. The typical kraft bleach plant utilizes five such stages. Countercurrent washing is used where the chemistry of the system will allow but there are generally at least two dilute streams from the bleach plant, acidic and alkaline.

The advantages of diffusion washing have been recognized for some time. If it were possible to add wash water or bleach chemical to the pulp stock at 15% solids and displace the liquid already mixed with the pulp, the dilution and rethickening steps could be avoided with consequent reduction in bleach plant effluent volume and reduction in energy consumption used in pulping the dilute stock and operating the vacuum thickeners.

In the past five years, the development of the so-called Kamyr diffusion washer has made possible application of diffusion washing to pulp systems. In operation an assembly of vacuum screens and liquid addition nozzles moves with the pulp on an upflow tower. At the end of the travel the "basket" snaps down in a few seconds to the bottom of the travel and then resumes its upward motion. In this way problems of blinding of the stationary filter surfaces by a moving pulp mass are avoided. The technique can be used either in washing of the brown stock from the pulp mill digestors, washing pulp from each of the bleach plant stages or in introducing and removing bleach chemicals in a single, multi-stage, upflow tower. There are a number of commercial examples of the first two applications and there is a 125 ton-per-day pilot plant in Finland operating on the third application. In this pilot plant, three stages of a bleach plant operation are conducted in one upflow tower.

In terms of the impact on pollution, there will probably be a small reduction in overall pollution because of the possibility of obtaining higher dissolved solids content in the mill effluent and thus alleviating effluent treatment problems. There should be a major impact on energy consumption because of the elimination of the need to dilute the pulp to wash it and consequent energy consumption in pulping the dilute pulp slurries and rethickening.

(2) All-Kraft Newsprint

Conventional newsprint is made up of 20 to 30% chemical pulp, such as semi-bleached kraft or unbleached sulfite, and the remainder is a high yield mechanical pulp. Such a paper is a high energy consumer because of the high content of mechanical pulp which requires a large energy input compared to kraft or other chemical fibers. Pollution problems arise from the dissolved organics from the water solubles in the wood and the air and water emissions from a semi-bleached kraft system. The basis weight of the conventional newsprint is about 30 lb/3,000 sq ft.

We believe that it would be technically possible to make an acceptable newsprint from an all-kraft pulp furnish, and at a much lower basis weight than the conventional newsprint. The conventional newsprint is made almost entirely from softwoods. Conceptually, the all-kraft newsprint would be made from 50% hardwood and 50% softwood semi-bleached kraft pulps with 10% of an opacifying filler such as clay and would be made in a 20 lb basis weight.

Such a newsprint would have a substantially lower energy input because of the substitution of high energy-consuming mechanical pulp by the low energy-consuming kraft pulp. Papermaking energy consumption would be lower because of the 20 lb vs. 30 lb basis weight. The overall air and pollution impact would be in favor of the conventional newsprint (i.e., higher air and water pollution load from the all-kraft system compared with the kraft-mechanical pulp system.)

The impact on wood consumption is more complex. Going from 30 to 20 lb basis weight would result in an immediate decrease in pulp consumption of 33%. The yield of kraft pulp is around 50% and the mechanical pulp over 90%. Thus, the quantity of wood used to make a square foot of newspaper would be about the same in both cases. However, the all-kraft newsprint furnish would utilize large quantities of the more available hardwoods and thus extend the softwood supply. In addition, it may be possible to utilize whole tree chips in the kraft system and make an acceptable pulp, whereas it is difficult if not impossible to remove the bark and other particles which would be obtained in the mechanical system from whole tree chips. Thus, the total yield of newsprint from an acre of woodlands might be considerably greater with the all-kraft furnish versus a mechanical pulp furnish.

The all-kraft news product is still in the conceptual stage. Laboratory work is needed to demonstrate that such a newsprint can be made satisfactorily. If it were technically possible to make the newsprint, the net impact would be a large decrease in energy consumption in newsprint, an increase in air and water pollution from the higher percentage of kraft pulp, a large increase in the consumption of hardwoods and, possibly, a decrease in the overall consumption of wood per unit area of forest land.

(3) Oxygen Pulping

The kraft pulping system, by far the most important chemical pulping process, contributes appreciably to both air and water pollution, partly as a result of the use of sulfur compounds as an integral part of the process. For this reason, there is a high degree of interest in non-sulfur pulping processes. One of these approaching commercial status is oxygen pulping.

In the kraft pulping process, a solution of sodium hydroxide and sodium sulfide is used to dissolve lignin from wood chips. The chemicals are recovered by evaporating the effluent from the cooking process, burning the organic material under reducing conditions, and causticizing the resulting smelt solution to regenerate sodium hydroxide and sodium sulfide. In one version of an oxygen pulping system the wood chips are softened under pressure treatment with sodium hydroxide solution and then the softened chips are disintegrated mechanically. The resulting raw, high yield pulp is then treated with high purity oxygen under alkaline conditions to complete the delignification. The effluent from the first alkaline treatment and the alkaline-oxygen delignification are combined, the resulting mixture evaporated, the organics burned in a recovery furnace, and the smelt from the recovery furnace causticized to recover sodium hydroxide cooking chemical.

The major incentive for the use of oxygen pulping is a reduction in air and water pollution levels; since there is no sulfur there are no malodorous organic sulfur compounds emanating from the system--either in air emissions or water effluent from the mill.

The yield will be about the same as with kraft pulping so there will be no reduction in wood consumption. Pulp properties will be somewhat inferior to those of kraft in terms of tear and tensile strength. Thus, the papermaking will have to make adjustments for the lower strength properties in using the pulp as a replacement for kraft. Such adjustments may involve additional energy consumption.

The alkaline oxygen stage will probably replace the initial chlorination stage in the multi-stage kraft pulp bleaching system. The effluent from the kraft chlorination stage and subsequent alkaline extraction is difficult to recover because of the high chlorine content and so it poses a pollution problem.

The alkaline-oxygen stage effluent, since it contains no chlorine, can be recovered and recycled to the recovery furnace. This factor results in an additional reduction in pollution load compared to the conventional kraft process.

Overall energy consumption for the oxygen pulping process combined with oxygen bleaching will probably be somewhat higher than for conventional kraft. Energy is required in the disintegration step of oxygen pulping. The overall energy balance on oxygen used for pulping and bleaching versus the power used for generation of chlorine in the conventional kraft system will probably show higher energy consumption for the oxygen pulping system. The energy derived from burning the dissolved organic material will be about the same in both cases. The overall result of replacement of kraft system with oxygen pulping will be somewhat higher energy consumption but a substantial reduction in air and water pollution load.

The first commercial oxygen pulp mill is being constructed by Weyerhaeuser at Everett, Washington. This mill will replace an existing sulfite mill of the same size. This particular installation may be justified on the basis that the kraft pulp will have properties similar to those of a sulfite pulp and Weyerhaeuser will gain experience in the use of oxygen in pulping and bleaching.

(4) Peracetic Acid Pulping

Another non-sulfur pulping process now under investigation uses peracetic acid and alkali as delignification chemicals. In an approach being pursued at Colorado State University, the chips are impregnated with peracetic acid solution and held for a period of time to allow the acid to react with lignin. The chips are then extracted with aqueous sodium hydroxide solution at the boiling point. Because of the relatively mild pulping conditions, yields of 60-65% are obtained on a laboratory level versus 42-45% with the kraft system. The peracetic acid pulp can be bleached readily--probably without the use of chlorine. The pulp properties are significantly higher than those of kraft pulp, especially with regard to tensile strength. With the peracetic acid pulping system, wood consumption is reduced dramatically--by 40+%. Air and water pollution are largely eliminated. However, the peracetic acid is a lacrymator and the air pollution problems which might arise from a commercial installation still need to be explored.

From the standpoint of energy consumption, the heat recovered in the recovery boiler will be considerably less than with the kraft system because of the higher yield and lower quantity of dissolved organic material. There will be no energy required to disintegrate the wood chips since they fall apart during the alkaline extraction stage. The economics of the process depend upon the development of a satisfactory method for recovery and regeneration of the peracetic acid.

The energy inputs required for regeneration of peracetic acid cannot be quantified now because the process has not been fully developed. Because of the higher strength property, it may be possible to use higher quantities of a lower quality pulp in combination with the peracetic acid pulp. The impact on energy consumption will need to be evaluated, but could result in lower overall energy consumption. The high yield peracetic acid pulp will beat more rapidly and so there will be some energy conservation in the stock preparation steps prior to papermaking. On balance, the peracetic acid system could result in large reductions in air and water pollution and wood consumption with relatively small increases in energy purchased.

This pulping system is still in the experimental stages. The pulping technology has been explored thoroughly but the peracetic recovery aspects are still in need of further development work in order to define a commercial peracetic pulping process.

(5) Thermo-Mechanical Pulping (TMP)

Recently it has been discovered that a superior mechanical pulp can be obtained if the wood is steamed at 260°F for a short time prior to mechanical disintegration and the mechanical disintegration step is conducted under pressure so as to keep the temperature around 260°F. Physical properties of the pulp are considerably superior to those of stone groundwood pulp and are better than those from atmospheric-discharge refiner mechanical pulp. Yields are slightly lower than for the conventional system--largely because of a slightly higher dissolved wood solids.

From a pollution point of view, there will be somewhat greater problem with TMP because of the higher quantity of dissolved organics. This probably will be of significance in the use of the process since the effluent from the pulping process is dilute (i.e., with regard to dissolved organics) and thus difficult to clean up.

With the TMP process, it is possible to make an acceptable pulp from wood residues which formerly were not suitable for mechanical pulp. The success of the TMP process opens up the possibility of using residue wood chips and sawdust for mechanical pulp from southern pine. Thus, the TMP process could extend the total wood supply by making it possible to utilize formerly unused wood.

The energy consumption in the TMP process is about the same as, or slightly higher than, the energy consumed in the refiner mechanical pulp process and significantly higher than in stone groundwood. Beyond this factor, the total impact of the TMP process on energy consumption will depend upon the way the process is utilized. It may be used to replace a portion of the long fiber pulp such as kraft used in a variety of furnishes. In this application, the net result could be substantial increase in energy consumption since the kraft process is a low energy consumer and the TMP, or any mechanical process, is a relatively high energy consumer. On the other hand, it may be used to process low grade residues such as sawdust and shavings. In this case, the physical properties are similar to those of stone groundwood and it would be used as a direct, one-for-one, replacement of stone groundwood. In this situation, the energy consumption would only be slightly higher for the TMP but there would be a substantial improvement in economy of wood utilization.

3. INDUSTRIAL ORGANIC CHEMICALS (SIC 2869) (OLEFINS)

a. Patterns in Energy Usage

The U.S. petrochemical industry is a very large and diverse industry. The degree of integration of the petrochemical industry varies greatly--those segments utilizing olefins as primary raw materials are normally closely integrated while those segments utilizing aromatics as feedstocks do not need to be integrated. The petrochemical industry is in general located near the source of the primary raw material. The industry as a whole is a fairly large user of energy for its processing operations, especially considering the energy content of the raw materials utilized for producing petrochemicals. It should be pointed out that the 1972 Census of Manufactures figures (for 1971) on fuels and electrical energy consumed do not consider the potential feedstock consumed by this industry as fuel. For example, the energy contained in the LPG and liquid feedstocks used in 1974 for producing olefins was equivalent to 984 x 10^{12} Btu - more than half the total energy purchased by SIC 28, Chemicals and Allied Products.

The petrochemical industry has been and still is a rapidly growing industrial segment. The products of this industry are essential to our way of life but the economic strength of the petrochemical industry is very dependent on the availability and cost of feedstock materials which compete directly with alternative fuel uses.

The petrochemical industry, in general, utilizes sophisticated and well developed technology. There are often a variety of techniques and processing routes for producing a given end-product. The more recently developed processes have been motivated by economic pressures to incorporate the use of lower cost raw materials, Other important changes in this industry have been the increasing size of production units in order to capitalize on the increased economic advantages of very large facilities.

Most petrochemicals are produced from three categories of raw materials - olefins, primarily ethylene, propylene and butylene; aromatics, primarily benzene, toluene and xylene; and methanol. These categories of raw materials are in turn produced from basic raw materials which are in themselves fuels. In 1974, 23.5 x 10^9 lb of ethylene was produced* using approximately 13-1/3 x 10^9 lb of ethane, 14.4 x 10^9 lb of propane, 2.6 x 10^9 lb of butane, 15.5 x 10^9 lb of naphtha and gas oil. Less than 0.5 x 10^9 lb of ethylene was recovered from refinery gases.

The aromatic raw materials used in the petrochemical industry are also derived from fuels. Benzene is the major aromatic used and in 1973 about 1.51 x 10^9 gal were consumed by the petrochemical industry. The sources of this amount of benzene were as follows:

Catalytic Reformate	50.9%
Pyrolysis Gasoline	15.8%
Hydrodealkylation of Toluene	27.1%
Coke Oven Operations	6.2%

The catalytic reformate is produced in refineries and the pyrolysis gasoline is produced in olefins units utilizing liquid feed products. In both refineries and olefin crackers, toluene is also produced and, since the requirements for benzene far outstrip those of toluene, toluene can be converted to benzene by hydrodealkylation.

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*Facts and Figures: The U.S. Chemical Industry, C&EN, 2 June 1975, pp 29-52.

Essentially all of the methanol produced in the United States uses natural gas as a feedstock material. Thus, it is apparent that, when the sources of the petrochemicals which are invariably fuels in themselves, are considered along with other fuel and electricity purchased by the industry, petrochemicals are a major factor in energy consumption in the United States.

If the feedstock is not considered as part of the energy utilized, the energy purchased in the petrochemical industry is highly variable. For example, in producing olefins, if ethane-propane cracking is utilized the energy requirements for the facility are approximately in balance. That is, no energy needs to be utilized in the operation outside of that contained in the feedstock. However, if naphtha cracking is used for producing the olefins, a lower yield of olefins is obtained but a net production of fuel is achieved. If gas-oil cracking is utilized, even more fuel is produced at a lower net olefin yield. If, however, an olefin production facility along with the secondary production units needed to convert the olefins into usable end-products is considered, the entire integrated complex is a relatively large user of fuel. In an integrated olefins complex, including downstream derivatives units, over 60% of the total manufacturing cost is attributable to energy costs when including feedstock as energy costs. Single units in an integrated facility, however, are highly variable in their use of energy.

b. Changes Anticipated

The petrochemical industry in general is already using energy in a relatively efficient manner. The current energy situation in this country will cause this industry to consider even more efficient use of energy but more importantly the use of more available and perhaps more economical feedstocks rather than the currently used feedstocks. For example, methanol is generally produced by reforming natural gas into a synthesis gas which is then converted to methanol. Synthesis gas, however, can also be produced from LPG, naphtha, heavy oils and coal. Because of the cost and availability of feedstock, future methanol plants may be based on using coal as the primary feedstock.

As previously noted, the feedstock required in 1974 for producing olefins was equivalent to 984 x 10^{12} Btu with almost 75% of this being supplied by ethane and propane. Most of the ethane and propane is recovered from natural gas and it is well known that our supplies of natural gas are diminishing. There is, however, the probability that the percent of ethane removal from natural gas will increase by use of cryogenic extraction techniques and that the supply of available ethane for olefins operations will remain about constant for a while. However, since the olefins industry has been growing at a rate of about 5% per year, it is generally agreed that the increased capacity of olefins production will come from the cracking of liquid feedstocks such as naphthas and gas oils. Hence, the major change foreseen in the olefins industry is one of feedstock. New plants will utilize naphtha or gas oil as feedstocks.

Generally, the more complex a feedstock is and the more impurities it contains, the more significant are the environmental problems associated with converting that feedstock to a usable product. For example, a facility producing olefins by ethane and propane cracking is relatively easier to make environmentally acceptable than is an olefin-producing facility which uses a gas-oil feedstock.

Generally, the environmental impact of an olefins plant is not severe. However, when going from an ethane-propane feedstock to a naphtha-gas oil feedstock, there are certain effluents which become more of a problem. For example, in the operation of the cracking furnaces, periodic decoking is required to remove the buildup of carbon which accumulates on the inside of the tubes in the cracking furnace. In the decoking operation there are normally effluents which contain hydrocarbons and carbon monoxide and must be cleaned up before release to the atmosphere. This buildup of carbon is slow in ethane-propane cracking but is fairly rapid when naphtha or gas oil is used as a feedstock.

In the quench system of an olefins plant used to cool the product gases from the pyrolysis furnace, different techniques are used depending on the type of feedstock. An ethane-propane cracking furnace normally will use a waste heat steam boiler followed by a direct water quench for cooling the product gases. An olefins plant processing naphtha or gas oil will often use a waste heat boiler followed by an oil quench system and then a water quench system to cool the product gases. The composition of the effluent streams from the ethane-propane cracking system is considerably different from those from a naphtha or gas oil system. When cracking naphtha or gas oil a considerably greater amount of complex heavier hydrocarbons is formed, presenting more problems in cleaning up the effluents.

A new technology is being developed to produce olefins directly from the cracking of crude oil and it is expected that some facilities will be constructed in this country for this purpose.

There have also been some recent developments on a process to produce acetylene from coal which may have a significant effect on the petrochemical industry in the future. Coal is, of course, our most abundant resource of energy and there are several obvious advantages to basing future expansion in the petrochemical industry on coal as a primary raw material. Furthermore, acetylene is a more reactive and, in some respects, more versatile raw material than ethylene. In fact, many of our major petrochemical products were based on acetylene as a raw material 15 or 20 years ago and the petrochemical industry switched from acetylene to ethylene as a primary raw material only because of the lower cost of ethylene. With the increased cost of petroleum feedstocks for producing ethylene, it may be that acetylene produced from coal will provide a lower cost route for producing such important chemicals as vinyl chloride monomer, vinyl acetate monomer, acrylonitrile and others.

The shortage of natural gas may also affect the raw material used to produce methanol, another large volume organic chemical. Methanol is produced from a synthesis gas which in turn can be made from propane, butane, heavier hydrocarbons and coal, as well as natural gas. It is likely that the shift for new methanol plants will be toward utilizing coal as a basic raw material.

The same pressures operating on the feedstock for methanol are also operating on the feedstock which will be utilized for producing ammonia. The technology and environmental energy impacts of producing ammonia would be similar to those studied in the production of methanol. Since the annual production of ammonia in 1974 was 15.7 x 10^6 ton and methanol production was only 3.4 x 10^6 ton, changes in energy usage in ammonia production would have a greater overall impact. [For a discussion of ammonia see our section on Ammonia and Fertilizers.]

Outside of the monomers for plastics and plastics themselves, ethylene glycol is one of the largest volume petrochemicals produced in the United States. In 1974 about 5.4 x 10^9 lb of ethylene glycol was produced. Ethylene glycol is normally produced by oxidizing ethylene to ethylene oxide which is then reacted with water to form ethylene glycol. There are two sources of oxygen for the ethylene oxidation, atmospheric air or high purity oxygen from an air separation plant. If atmospheric air is used as a source of oxygen, the plant does not require any purchased energy, but if high purity oxygen is used, purchased energy is required. However, the yield of ethylene to ethylene glycol is higher when high purity oxygen is used, so if the energy contained in the feedstock is considered, the processes are not significantly different in the total energy requirements.

A rough estimate of the energy requirements for producing ethylene glycol indicates that about 60 x 10^{12} Btu per year are purchased for this industry. Of this, about 10% is in the form of electrical energy and the balance fuel.

There are very few effluent problems associated with operating an ethylene glycol plant which uses high purity oxygen as the oxidant, and most of the ethylene glycol producers in this country are believed to utilize high purity oxygen as the oxidant. If, however, air is used as the oxidant, the vent stream of the residual, unreacted oxygen along with the nitrogen in the air must be cleaned up before it is discharged to the atmosphere.

New technology is being discussed in the literature for producing ethylene glycol directly from ethylene without having to isolate ethylene oxide as an intermediate. However, little is known about this technology and it is not expected to have a significant impact on the industry in the next several years. Still, it may have long term potential. It is also very unlikely that this new technology will displace existing plants. It would more likely be utilized in new plants constructed in the future.

Therefore it is felt that the probability of process changes in the ethylene oxide-ethylene glycol industry is small and, even if the changes occur, their energy ramifications are small.

4. CEMENT, HYDRAULIC (SIC 324)

a. Change to Coal from Gas and Oil

One of the major changes which is occurring in the United States portland cement industry today is the rapid conversion of plants from the use of gas and oil fuel firing of their rotary kilns to the use of direct coal firing.

The kiln is by far the largest consumer of energy in the portland cement manufacturing process. The chemical change which is required to convert the raw materials into cement clinker occurs in the kiln. Major kiln fuels are coal, natural gas, and residual fuel oils. The second largest energy consuming unit process in portland cement manufacture is in the form of electricity for grinding the raw materials to a fine powder before they are fed to the kiln, and also for grinding the clinker produced in the kiln to a fine powder, which is the finished cement product. Presently the fuel energy required in the clinkering step represents approximately 80% of the total energy required for manufacturing portland cement. The remaining 20% is required for the raw material and finished cement grinding steps.

The consumption of fuel by type for the burning of clinker in rotary kilns in the U.S. cement industry is presently approximately:

Natural gas = 45%
Coal = 40%
Oil = 15%

All rotary kilns are suitable for coal firing, and it appears that changes only in the ancillary facilities such as coal storage handling and grinding must be added to a plant which is switching from gas or oil to coal firing.

Since a large fraction of the coal ash from a coal-fired cement kiln is combined with the clinkering raw materials, the use of coal actually combines the fuel stream to the main reactor (the kiln) with the raw material stream. Therefore, a suitable adjustment must be made in the proportioning of the various raw material components going into the rotary kiln raw feed mixture, to account for the additional iron, silica and alumina values coming from the coal ash.

Most of the sulfur values contained in the coal are absorbed by the lime in the rotary kiln, and become part of the cement produced. Although this is beneficial from an emissions standpoint in reducing SO_2 emitted to the atmosphere from the kiln stack, it can have a detrimental effect on the quality of the cement, since a maximum sulfur content for cement is specified. The two main sources of sulfur in cement are the clinker itself, containing sulfur from the fuel, as well as gypsum which is added to the clinker when the finished cement is ground. The gypsum is added to control the setting time of the cement. Consequently, as the sulfur content of the clinker increases, the maximum quantity of gypsum which can be added to control the physical characteristics of the cement must decrease to stay within the prescribed ASTM specifications for portland cement. So, excessive sulfur contained in the clinker can have a detrimental effect upon the cement by limiting the gypsum added to a level necessary to produce the desired characteristics of the finished cement.

The coal ash which does not become combined with the clinkering raw materials in the rotary kiln leaves the reactor in the combustion gases along with the kiln dust, and therefore can change the physical and chemical characteristics of the dust collected from that gas stream before it is discharged to the atmosphere. Proper handling and disposal of this dust can be significantly affected by the presence of coal ash.

b. Change from Wet Process to Dry Process

Today, roughly half of the portland cement produced in the United States is produced by the wet process, with the remainder being produced by the dry process.

In the wet process, raw materials with high moisture content as quarried are wet-ground to a slurry form, which is fed to the rotary kiln. In the dry process, relatively low moisture-containing raw materials are ground in a dry form to produce a powder which is introduced to the rotary kiln. As one would expect, the evaporation of water from the slurry in the wet process requires additional heat. In 1973, the average fuel consumption for the wet process was 7.8×10^6 Btu/ton, compared with only 6.8×10^6 Btu/ton for the dry process. Therefore, switching from wet-process to dry-process plants will have a significant impact upon energy requirements in the domestic cement industry. Also, the most significant source of water pollution in the manufacture of portland cement comes from the discharge of water from wet-process cement plants, so that switching to the dry process would reduce pollution problems.

c. Suspension Preheaters

The suspension preheater is not a simple heat recuperative device added on to a kiln; instead, it is actually part of the reactor in which all of the various chemical reactions and physical changes occur in the raw materials as they are heated and processed into cement clinker. A suspension preheater-equipped rotary kiln is typically much shorter in length than a conventional straight rotary kiln, since much of the utilization of heat, processing, and chemical reactions occurs within the vessels of the preheater itself. Therefore, the preheater replaces a large part of the feed end of the rotary kiln.

The cement kiln preheater was developed in Germany in 1950. Since that time, over 500 suspension preheater kiln installations have been built, but only a small number (22 units) were sold in the United States through 1971.

d. Flash Calciners

The flash calciner represents an even more substantive change in the design of the rotary kiln or cement reactor than does the suspension preheater-equipped rotary kiln. In the flash calciner, approximately 50% of the total fuel is burned in the calciner, and up to 90% of the total calcination of the calcium carbonate contained in the raw material is accomplished in this unit before the raw material enters the kiln.

The reported major benefits of the flash calciner are:

- Throughput of an existing suspension preheater kiln can be more than doubled without additional firing of the kiln.

- Large-capacity plants can be built with small kiln dimensions, resulting in the possibility of lower fixed capital investment, and also extending the life of refractory brick (which falls off dramatically as kiln size increases).

- Higher fuel efficiency can be attained than with suspension preheaters.

- The generation of nitrogen oxides is reduced by both the low temperature and the short time the combustion gases stand in the burning zone, relative to conventional kilns, where all fuel is fired at clinkering temperature of 2700°F. Therefore, the NO_x emissions from one of these systems could be significantly lower than emissions from conventional preheater kilns or standard long-kilns.

e. Roller Mills for Raw Material Grinding

Today's state-of-the-art in cement manufacture is undergoing a significant change in the raw material grinding step. Most of the cement mills in the United States today use closed-circuit ball mills for grinding the raw materials (dry-process plants). The air circulated through these ball mills, and then through the series-coupled air separator or classifier, is usually heated by the addition of combustion gases from an oil-fired furnace. This is done to dry the raw materials for proper grinding and classifying. A roller mill teams up with a flash calciner especially well. After the kiln off-gases have heated raw materials entering the kiln, the gases can be further utilized in a roller mill for removing moisture from other raw materials. A ball mill is unable to match a roller mill in gas handling capability, and hence drying ability. Also, it is reported that energy savings with a roller mill are between 25 and 35% over today's ball mill.

f. Switch from Portland to Other Hydraulic Cements

Approximately 95% of all of the hydraulic cement used in the United States is portland. Of the remaining 5%, however, there are several types which require less energy in their manufacture than does portland and thus may be an important alternative as energy costs increase. These cements are used extensively in South America and Europe and have physical characteristics which are desirable and quite competitive with portland cement. Both of these categories of hydraulic cements can contain as much as 56% of the reactive additive.

Examples of these cements are as follows:

- Pozzolanic Cements. Naturally occurring and active minerals, or artificially produced substances such as fly-ash, react with lime in an aqueous solution to produce a material with hydraulic cementitious properties which can be used as an additive to portland cement.

- Slag Cement. A reactive slag such as blast furnace slag, from the iron and steel industry, can be used as an additive to portland cement, producing much the same result as Pozzolanic cements.

The primary energy related impact of the manufacture and use of such cements is that blast furnace slag or other naturally occurring pozzolanic materials enter the portland cement manufacturing process only at the final grinding step. Therefore, it is not necessary to subject them to the large energy consuming processing steps of clinkering in the rotary kiln, or raw grinding. A shift toward the increased use of such hydraulic cements would have a significant energy conserving impact, and would also reduce pollution problems per ton of cement produced. The increased use of these cements would also provide a beneficial and economic use for such waste materials as blast furnace slag or fly ash, thereby tending to reduce the environmental problems associated with these waste materials.

g. Fluidized-Bed Process

An alternative to the rotary kiln or vertical shaft kiln for use in producing portland cement clinker is the fluidized-bed reactor. The fluidized-bed process has been developed in this country, and demonstrated in a semi-commercial-scale facility with a production capacity of 100 ton/day cement. It has also been studied at the large pilot-scale level in Germany and Japan. This work has been carried out during the past fifteen years and has resulted in a technically successful new process. There are, however, no commercial installations using this process at present.

One of the important aspects of this new process is its ability to produce acceptable portland cement clinker from discarded kiln dust, which cannot be done by today's rotary kiln state-of-the-art. The main reason that kiln dust is unacceptable in today's rotary kilns as the exclusive raw material feed (even if it were chemically balanced to produce cement clinker) is the presence of high amounts of potassium and sodium sulfates, commonly referred to in the cement industry as "alkalies."

The fluidized-bed process volatilizes such a high amount of alkalies from the raw material fed into the reactor, that even kiln dust with its high alkali content can successfully be converted into portland cement clinker of acceptably low alkali content (0.6 wt % expressed as sodium oxide equivalent). The volatilized alkalies are carried from the fluidized-bed reactor by the existing combustion and fluidizing gases, and condense into a fine particulate material which can be removed from the gas stream by means of a glass cloth filter. Because of the ability to make acceptable portland cement clinker and a relatively pure potassium and sodium sulfate byproduct from high alkali waste dust, this is an important candidate process for significantly reducing the problem of waste kiln dust disposal in an economical and technologically feasible manner.

h. Cold Processing

This process represents a radical departure from today's state-of-the-art in that no high temperature processing is involved. Its inventors are C.J. Schifferele and J.J. Coney. In their process, quicklime and an argillaceous component (to supply alumina and silica) such as a shale or clay are chemically combined by grinding in a conventional ball mill. Rather than representing a change in one of the key unit processing steps, this departure from conventional cement-making technology represents an entirely new processing route.

This process has been demonstrated at the pilot-scale level, and is reported to produce a hydraulic cement of characteristics and properties which compare favorably with portland cement. The obvious advantage of such a process is the significantly reduced fuel energy requirement, since the only thermal processing necessary is for calcining limestone by conventional means. The main electrical energy required is for grinding the quicklime with the other components.

From an environmental standpoint the quantity of dust per unit of final cement produced would be less than that associated with portland cement, since only the limestone (rather than all of the raw materials) is burned in a kiln.

i. Oxygen Enrichment

The simplest way to increase cement capacity from an existing rotary kiln is by oxygen enrichment of the combustion air. We understand that this is presently being practiced in several cement plants in the United States. If heat losses through the shell of the kiln remain roughly constant, and the cement clinker output is increased through oxygen enrichment, there should be a decrease in the unit fuel consumption. This probably has implications regarding the generation of NO_x, due to the higher flame temperature and reduced nitrogen concentration of the combustion gas. Also, the quantity and chemical composition of the dust leaving such a kiln operation would probably be different from a conventional system.

The use of oxygen also should permit the use of special fuels, such as petroleum coke, which may have implications concerning the quantity of sulfur in the kiln gases and in the cement product when high sulfur petroleum coke is used. Finally, oxygen enrichment should permit maintaining proper burning characterisitcs of the flame when using large quantities of recovered dust, which could be recycled in order to cut raw material wastage, or in order to comply with dust disposal regulations.

5. PRIMARY ALUMINUM (SIC 3334) AND ALUMINA (SIC 2819)

a. Background

The primary aluminum industry is a major consumer of energy as evidenced by the fact that this industry has historically ranked in the top ten energy consuming industries at the 4-digit SIC code level. The industry's energy consumption is primarily in the form of electric power. The total aluminum produced in the United States is about 80% from primary production and the remainder from secondary (scrap) production, so it is the primary aluminum industry that is the major power consumer.

The production of primary aluminum is a 2-step process. Bauxite, the raw material for the primary industry, is first converted to alumina in large hydrometallurgical Bayer plants. The resulting alumina is reduced to aluminum metal by the Hall-Heroult process in aluminum reduction plants. Approximately 4 tons of bauxite are required to produce 2 tons of alumina in the Bayer process plants. Approximately 2 tons of alumina are required to produce 1 ton of primary aluminum metal. Bayer alumina plants are relatively minor consumers of energy (11.5×10^6 Btu fuel and 300 kWh power/ton of alumina), while the aluminum reduction plants are major consumers of energy (11.5×10^6 Btu fuel and 16,800 kWh power).

Table B-5 shows that the production of 1 ton of primary aluminum has roughly the following energy requirements per ton of primary alumnum for plants built prior to 1970.

TABLE B-5

TYPICAL FUEL AND ENERGY REQUIREMENTS IN PRODUCTION OF ALUMINUM

			Fuel 10^6 Btu	Power kWh
Alumina Production	Fuel	11.5 x 2	23	
	Power	300 kWh x 2		600
Aluminum Production	Fuel	11.5	11.5	
	Power	16,800		16,800
Totals			34.5	17,400

Because aluminum production plants are large consumers of power, the industry has historically located its reduction plants near sources of low cost power (hydroelectric projects) or sources of low cost fuel ("mine mouth" coal or low cost natural gas). The industry has always recognized the importance of reducing electrical energy consumption and through the years has made some gains in reducing power consumption as a result of:

- Replacing the higher power-consuming, older Soderberg pot lines with the more efficient prebaked anode reduction cells.

- Use of larger cells that permits reduction of heat losses per ton of aluminum and lower current densities and therefore less reoxidation inefficiency at the anode.

- Minor improvements in efficiency through reduction in electrical resistance losses in the anode and cathode electrical connectors.

Much of the existing aluminum reduction capacity was built prior to 1970 and, as stated earlier, typical power and fuel requirements for these plants were 16,800 kWh and 11.5×10^6 Btu/ton. Typical power and fuel requirements for new or modified plants are 14,800 kWh and 12.9×10^6 Btu/ton. This represents a 12% reduction in more expensive electrical energy but an equal increase in thermal energy. The increase in thermal energy is due largely to increased fuel requirements for prebaking which was formerly accomplished in the Soderberg pot with electrical energy.

These improvements were accomplished during the late 1960's and early 1970's, a period when energy costs were rather stable and there was not the incentive to reduce energy consumption that there is today. Now with a higher incentive for reducing energy consumption, and in particular, electrical energy consumption, there are real prospects of more significant changes in the processes for producing primary aluminum. Most of these changes are directed at reducing energy consumption but some are concerned with using domestic alumina-bearing clay reserves to reduce the balance of payments problem. This is a real issue since almost all aluminum produced in the United States originates from foreign sources of bauxite.

(b) Potential Process Changes

The potential process changes currently under development or consideration are:

(1) Alcoa's aluminum chloride electrolysis process. This process is expected to reduce electrical energy consumption by 30% and to eliminate the consumption of anode carbon.

(2) Replacement of the carbon cathode in the conventional Hall-Heroult cells with refractory hard metal cathode made of titanium carbide or titanium diboride. This process modification is expected to reduce electrical energy consumption per ton by 20%. At the same time it may substantially increase power input to the cells which will result in equivalent increases in production per cell. The net result of this modification would be substantial reduction of capital requirement for future expansions.

(3) Several proposed acid leaching processes for recovering alumina from abundant reserves of domestic clays in the United States. These processes are generally similar in concept but vary with respect to the acid used. Processes involving leaching of kaolin clays with nitric acid, hydrochloric acid, sulfurous acid, and a combination process involving the use of sulfuric acid for leaching followed by conversion of the aluminum sulfate to aluminum chloride have been developed. At least three of these are currently being tested on pilot-plant scale by the U.S. Bureau of Mines.

(4) The Toth Process based on chemical rather than electrolytic reduction of alumina. This process as proposed could also be based on domestic clay reserves. The clay, mixed with coke, would be chlorinated with recycle chlorine to aluminum trichloride which would then be reduced with manganese metal to aluminum metal and manganese dichloride, which in turn would then be oxidized to manganese sesquioxide to produce chlorine for recycle. The manganese sesquioxide would be reduced in a blast furnace to manganese metal for recycle. Aspects of this process are questionable but, in view of the amount of publicity and controversy it has generated, an investigation of its potential would be an essential part of the industry analyses.

All of the potential process changes described above will have environmental implications. Even the modest modification of the carbon cathode in the conventional cell to titanium diboride would have implications because the present systems for control of fluoride emissions may be inadequate if production is increased.

Since two of the four potential process changes mentioned above involve changes in raw material, any investigation of the industry should include production of both alumina and aluminum metal. However, since alumina produced for aluminum reduction represents 93% of all alumina (SIC 2819) produced in the United States, (i.e., excludes that for refractory chemical, abrasives, etc.) we do not propose any investigation of the relatively small amount of alumina produced for purposes other than for aluminum production.

6. PETROLEUM REFINING (SIC 291)

The U.S. petroleum refining industry can be characterized as a mature, stable industry which is a large user of energy (approximately 10% of the energy content of hydrocarbon inputs to refineries is consumed in the manufacturing process).

The refinery industry has been extremely alert in optimizing the use of existing facilities by continually reviewing opportunities to increase product revenues (such as changing product mix to produce higher value products like gasoline) or improving product qualities (such as increasing gasoline octane number or reducing fuel oil sulfur content while minimizing raw material and operating costs). Within this context, internal energy consumption will be minimized since purchased electricity, natural gas, or steam are direct operating costs and if it is necessary to supply marginal energy from a portion of the crude oil barrel (because of the lack of availability of purchased natural gas) this will be reflected as a change in raw material costs.

It has always been profitable for refineries to minimize energy consumption and within the industry unit energy consumption has remained relatively constant per barrel of refined product over the last 20 years, even though plant processing complexity has increased substantially over the same period. The economic incentive to continue this trend will be increased as the refining industry's access to relatively cheap natural gas for energy use diminishes. Since in the future the marginal energy supply for refining use will come from a portion of the crude oil barrel, internal refinery unit energy costs will increase by a factor of approximately 8-10. The major efforts to achieve energy conservation already practiced will be pursued even more aggressively in the future and consist of:

(1) Greater heat exchange recovery, either by installation of additional surface area or by making more effective use of existing equipment (such as improving the average heat transfer coefficient).

(2) Increasing thermal efficiencies of direct fired heaters/boilers by installing additional surface area in convection sections, reducing excess air, etc.

Higher unit energy costs will also accelerate the program of recovering energy from catalytic cracker regenerator exhaust gases by installation of carbon monoxide heater/boilers and/or expander turbines. Installation of these facilities has a favorable environmental impact in that it decreases emission of carbon monoxide and catalyst particulates.

There are two competitive processing sequences in the United States for converting or upgrading heavy oils to lighter products. These are catalytic cracking and hydrocracking. Most of the present U.S. refining in the industry incorporates catalytic cracking, a process developed in the mid-1940's. The hydrocracking process did not become commercial until the 1960's. Both processes can achieve about the same conversion in product mix. The hydrocracking process requires greater investment but produces a higher yield of premium quality products. Thus, to the extent that unit energy costs have inflated more than capital investment, we would see a trend toward utilization of hydrocracking in the U.S. refining industry. The economic incentive for this, however, is not sufficient to justify wholesale replacement of existing facilities that are in good operating condition. This trend should become apparent only in new grassroots installations or in replacement of existing catalytic cracking facilities that have exceeded their "useful" economic life.

There are several uncertainties which will affect future energy consumption patterns in U.S. refining and resultant environmental emissions. Among these are:

(1) The likely adjustment of U.S. refining yields to more closely balance the total demands of the domestic marketplace and thus produce more residual fuel oil. This will reduce required processing complexity.

(2) The need for higher quality products in the marketplace, such as, increased clear pool octane numbers for motor gasolines and lower sulfur contents of fuel oils.

(3) Increased environmental restrictions regulating emissions into the air and water and/or solid wastes from the refining industry.

(4) As supplies of indigenous high quality crude oils diminish, they will likely be replaced with poorer quality crudes from Venezuela and the Middle East. This trend will be accelerated if Canada proceeds with its announced program to integrate Western crude oil production with refining demands in the East via pipeline construction. This would mean replacing approximately 1 million barrels a day of relatively good quality Canadian crude now available to U.S. refineries with poorer quality crude from other foreign sources.

(5) Curtailment and/or elimination of natural gas supplies available for refinery use.

This latter factor could have the most significant effect on refinery energy usage with environmental implications. The main uses of natural gas in refining operations are as fuel for process heaters/boilers and as feedstock for hydrogen manufacture. Initially it is most likely that natural gas will be replaced with liquid petroleum fractions. However, in the medium to long term future, it may not be desirable to use liquid petroleum streams for these purposes and the possibility of eventual replacement with coal exists.

Refinery hydrogen is used in two basic processes--hydrocracking and hydrotreating. In the hydrocracking process heavy petroleum oils are converted to lighter, higher valued products. The hydrotreating process improves product quality of a petroleum fraction by removal of sulfur, nitrogen and other undesirable impurities. Since the U.S. refining industry will be processing poorer quality crude oils, more hydrogen will be used for the above purposes. A key point is that, if the U.S. refining industry continues its present high conversion processing sequence, hydrocracking will be an important process. If the U.S. refining industry is modified to less conversion and produces higher yields of residual fuel oil, then desulfurization of fuel oil will become an important process. Thus, no matter which scenario evolves, refinery hydrogen requirements will increase and the problems associated with converting coal to hydrogen could become a major issue in analyzing trends in refinery energy consumption with environmental implications.

7. TEXTILES (SIC 22)

a. Introduction

The textile industry (SIC 22) consumes about 2.8% of the purchased fuels and electrical energy required by all major industry groups surveyed by the Census of Manufactures, and ranks about ninth in individual industry energy use. About 30% of this demand is for electrical energy and the remaining 70% is supplied by distillate and residual fuel oil, natural gas, propane, and coal. Dyeing and finishing operations consume about 60% of all the energy used in producing textiles, relying heavily on propane and natural gas as a fuel source. The other processes, such as spinning, weaving, and knitting, consume the remaining energy, primarily in the form of electricity. Demand for energy in the textile industry is expected to increase in line with population growth and consumer demands. Textile industry sources estimate that total energy equivalent to 39.7×10^6 barrels of oil was consumed by textile manufacturing in 1973 and that without additional energy conservation consumption will grow to the equivalent of 52.5×10^6 barrels by 1980. This represents an increase in consumption of about 32%.

Much of the energy required is used for heating water for dyeing fiber or fabric and for subsequent washing and drying operations. Therefore process changes which reduce or eliminate water use will have a major positive impact on energy conservation. Major process changes either under development or already in limited use commercially which satisfy these goals are described below.

b. Solvent Processing

Solvent processing offers the prospect of substantial savings in energy over conventional aqueous processing because 15 times more energy is required per pound to vaporize water than to vaporize typical solvents, such as perchloroethylene. For example, one pound of water requires 1,162 Btu for vaporization against only 135 Btu for the same quantity of perchloroethylene. Further, since non-aqueous solvents have higher vapor pressures, drying rates are appreciably faster and less energy is required.

(1) Sizing and Desizing

Sizing, such as starch or polyvinyl alcohol (PVA), must be applied to yarn to give it sufficient strength for the weaving operation. Solvents can replace the aqueous medium now used to apply size to the yarn. Solvent desizing operations constitute a reversal of the sizing process in which pure solvent removes the size after weaving, leading to the potential recycle of the sizing compound.

(2) Scouring

Solvent scouring to remove impurities is also being tried, particularly for some knitted goods prior to dyeing. In some cases solvent processing offers the further advantage that several operations may be combined, as in the "Markal" process for the simultaneous scouring, desizing, and bleaching of the textiles.

(3) Dyeing

Nearly all textile dyeing is now performed in an aqueous medium. However, the "STX" solvent beam dyeing process for carpets can dye most synthetic fibers except dispersed dyeable polyester. Complete exhaustion of the dyestuff is achieved by gradual azeotropic distillation and recovery of a small fraction of methanol used to solubilize the dyestuff in perchloroethylene. The solvent can then be returned for reuse even without distillation. Solvent vapors evolved during drying are collected and returned to the mixing tank. Thus essentially all the solvent is recovered and recycled, and there is no solid residue for disposal. A major drawback, however, to present solvent dyeing systems is that they have not yet been adapted for dyeing polyester which appears to be a major growth fiber of the future.

(4) Finishing

Solvent finishing processes, e.g., "Varsol," are well known and some finishes such as silicone polymers can only be applied from solvents. Application of stain and soil resistant finishes to upholstery fabrics by solvent processing is also becoming more common. However, many finishes are still applied in aqueous solutions at elevated temperatures. This offers further potential for energy conservation by extension of solvent processing methods.

c. Hot Melt Sizing

Another sizing method under development is hot melt sizing which consists of applying the melted size to the yarn by a series of heated transfer rollers. Since very little water is required, this reduces the energy requirements and the water pollution potential. Another advantage is that the equipment occupies about half the volume of conventional sizing equipment. Desizing of hot melt sized yarns can be accomplished by conventional aqueous desizing methods or more probably by solvent desizing systems.

d. Dyeing Processes

Other dyeing processes with potential for energy conservation include the "Thermasol" pad, high temperature fixation process where the dye is applied directly to the fabric from a roller, and the "Sancowad" process. The latter utilizes dyeing at very low aqueous liquor ratios from a stabilized aqueous foam, reducing water consumption by as much as 90% and the accompanying energy costs by about 65%, compared to conventional dyeing operations.

Vacuum impregnation has been found useful in the dyeing of certain materials. The use of vacuum to remove air from the fabric results in a more rapid and even dye penetration, hence the dyeing times are considerably reduced. Dyeing at elevated pressures in "becks" or jet machines leads to reduced water use, reduced dyeing times, and lower chemicals consumption. All these factors assist in energy conservation.

e. Washing Operations

A substantial fraction of the energy used in textile operations is to provide hot water for washing and rinsing between other process operations. Therefore, more efficient washing assumes a high priority. This can be achieved by the use of more effective continuous countercurrent rinsing operations which requires the wider application of new equipment. Rinsing at slightly elevated pressures in continuous equipment has also been proposed to provide more efficient removal of chemicals such as sodium hydroxide used in mercerizing operations. Development work is being conducted on the use of turbulence, sonics, and other means of assisting with dirt and excess dye removal, potentially resulting in lower energy requirements.

f. Direct Drying

Wide use is made of natural gas for direct infrared dyeing of textile materials. Electricity can be substituted for the natural gas and a more recent development is the use of microwave drying. This technique is attractive because the microwave energy is preferentially absorbed by the water present in the fabric and gives uniform drying throughout the fabric, thereby lowering dye migration effects. In order to further reduce the heat energy required for drying, a variety of mechanical techniques can be used to remove the maximum amount of water in the fabric before the application of heat. Squeezing between mechanical rollers will reduce water content to 50-100% of the dry fabric weight. Further water can be removed by the use of porous rollers which reduce water content by capillary action. This technique has been demonstrated, but not widely applied.

g. Environmental Considerations

The textile industry has its major pollution problems in the area of water; furthermore, the large number of small plants make the industry especially sensitive to the impact of energy costs and the costs of pollution control. Consequently, process changes which conserve energy while reducing wastewater should be especially attractive. On the other hand, the type and nature of the chemicals used might significantly change the nature of the pollutants discharged, e.g., increased emission of photoreactive chemicals to the atmosphere or change in the toxicity or hazard of waterborne pollutants.

8. GLASS MANUFACTURING (SIC 3211, 3221, 3229, 3296)

a. Industry Classification

The manufacturing of glass and glass products is a large, widely diversified industry in the United States. The Standard Industrial Classification (SIC) is a helpful but not comprehensive guide for segmenting the glass industry. The greater portion of glass manufactured products falls under the SIC 3-digit classifications 321 and 322. However, an important segment of the U.S. glass industry is the manufacture of glass wool products, which is listed in SIC 3296. Another consideration in defining the industry segment of highest priority in this discussion is the relative energy consumption; therefore, those manufacturing processes involved in producing products from purchased glass and those that require relatively minor quantities of energy are of less interest.

In order to effectively examine the energy intensive large volume production of glass, the industry has been viewed more in terms of the industry structure than on the basis of the SIC numbers. Thus, the segments of the industry have distinct products, sell into different markets, are made with different technology, and involve specific companies.

The segments of the glass industry covered in this discussion are:

Flat Glass	(SIC 3211)	including sheet, plate and float, laminated, tempered automobile glass
Glass Containers	(SIC 3221)	food, beverage, pharmaceutical glass
Pressed and Blown Glass	(SIC 3229)	tableware, T.V. bulbs, lamp enclosures, tubing, etc.
Fiber Glass	(SIC 3229 and 3296)	continuous textile grade and wool fiber glass.

b. Industry Background

In three of the major sectors of the glass industry - flat, container and fiber glass - the industry is highly concentrated in a few large companies. Some of these companies are multi-product and even multi-industry, such as PPG Industries, Ford Motor Company, and Owens-Illinois. In the pressed and blown sector there is a wide diversity of company participants from large integrated corporations to small independent producers using nonautomated techniques.

The total value of the production from this industry is about \$4 x 10^9. Historically, the growth has been at a rate of approximately 3.5% per year over the last 25 years, a little less than Gross National Product. The major factor that dominates the industry's growth is the growth and economics of the principal markets: construction, automotive, packaging and consumer products. Significant growth in the container glass industry resulted in the last decade from the use of nonreturnable glass beverage bottles. That sector of the total glass industry represents about 45-48% of the total output of the industry. Flat glass is about 15% of the industry and fiber glass and pressed and blown glass each represent about 20% of the total output. The total number of plants of any significant size in the industry is approximately 400.

Two historical facts are evident in the glass industry's structure and characteristics. First, a single glass company produces in one of the major sectors listed above with only a few of the larger companies manufacturing in two. By and large different companies participate in different sectors, i.e., Owens-Corning is in fiber glass, Libby Owens Ford is in flat glass, and Owens-Illinois is in glass containers. Second, plants have traditionally been located near sources of raw material (principally glass sand) and skilled labor and in the general vicinity of major markets. Thus, the Midwest has the highest concentration of glass plants in all sectors. More recently with shifts in population and markets away from the Midwest and East coast, glass plants are being constructed in areas of market growth, the Southeast, Southwest, and Pacific coast. Also, highly automated production reduces the dependency on highly skilled glass makers.

The total energy consumed by the glass manufacturing industry, according to 1972 Bureau of Census data is about 80 x 10^9 kWh of purchased fuel and electrical energy. This places glass manufacturers high among the most energy intensive industries in the United States. 50% of the total energy consumed in glass manufacturing is within the glass container segment of the industry. More recent estimates have placed the current total energy consumption of this industry at $\sim 88 \times 10^9$ kWh.

In the past 25 years, energy consumption in the glass industry has grown at a lower rate than the total industry output. The useful energy required per unit of product over that time period has dropped from 46 kWh per 1967 dollar of product to 25 kWh per 1967 dollar of product, which is an average annual rate of 1% per year. The increased efficiency of energy use is due to the trend toward larger furnaces, increased use of waste heat, forming process automation and an increase in the market for lightweight glass containers.

The type of energy utilized by the glass industry has also undergone some change in the last 2-1/2 decades. In 1947 natural gas was 65% of the total, oil 13%, electricity 3%, and coal 18%. Of the total energy sources used today, it is estimated that 86% is derived from natural gas, 3% from oil, 8% from electricity, and 1% from coal.

c. Glass Manufacturing Process

Although the glass industry produces a large number of different products and serves quite different end-use markets, there are common features in the production process. The major unit processes may be viewed as follows:

- Raw materials handling and batch preparation
- Melting
- Refining
- Forming
- Finishing

The first three process steps of batch preparation, melting, and refining are quite similar throughout the glass industry although refining may differ in degree for processes producing different products such as flat glass, where optical homogeneity is extremely important, and fiber glass, where the presence of fine bubbles is not as critical. Batch preparation is not a significant energy consuming process step. However, melting of the raw materials to form a viscous glass melt consumes approximately 70-75% of the total energy used in glass production. The refining step, which accomplishes the homogenization of the melt, accounts for 5-10%, and forming and finishing, principally annealing, for 15%. The remaining energy is consumed in ancilliary equipment. Melting and refining are carried out in the large continuous furnace and it is this process step that will obviously receive the greatest attention in attempts to conserve energy through process change.

Other factors that have been considered such as feedstock changes do not appear to offer any great opportunity to conserve energy. The compositions of commercially useful glass have evolved over a long period of time and are designed to meet requirements for transparency, corrosion resistance, strength, etc. Raw materials are generally plentiful and low cost. In no case are the mining and extraction of the raw materials particularly energy intensive.

d. Potential Changes in Melting and Refining of Glass

All major operations in the production of glass utilize the continuous open-hearth type of furnace for the melting and refining of glass. The size of these refractory furnaces ranges from capacities of less than 100 ton of glass per day to 500-600 ton/day. By and large these furnaces are end- or side-port fired regenerative furnaces with checker systems to retain the waste heat and to reheat the combustion air during the reverse cycle. In the United States 85-90% of the furnaces are fired with natural gas. The energy consumption to melt glass varies significantly from plant to plant (due to product requirements and efficiency of operation) from 7 x 10^6 Btu/ton to 14 x 10^6/ton.

In the short term the trend will no doubt be to replace natural gas with oil and possibly with use of supplementary oxygen. Heavy fuel oil is quite acceptable as an alternative to natural gas for melting glass. However, special problems require that sulfur content be 2% maximum and vanadium as V_2O_5 be no greater than 200-400 ppm. Refractory wear is considerably increased especially with high sulfur containing oil. Further, oil flame temperatures and velocities are greater than with natural gas and result in increased NO_x, SO_2/SO_3 and particulate emissions and higher volatilization from the glass melt. On the other hand, waste gas heat losses will be lower with oil firing than with natural gas and oil flame emissivities are greater, giving improved melting rates. Extensive experience with oil fired glass melting furnaces in areas of Western Europe exist and this experience could be a useful source for comparison.

Although limited work has been done with oxygen enrichment of combustion air for fossil-fuel fired glass furnaces, this technique offers a potential energy saving. The output of existing furnaces can be increased and the energy per unit output can be decreased with oxygen enrichment. In one particular case, fuel consumption was decreased as much as 0.6 x 10^6 Btu/ton through the use of oxygen, representing about an 8% decrease in energy consumption.

A second short term alternative is the use of electric boosting of fossil-fuel fired glass furnaces. This technique has been useful in increasing capacity in existing furnaces without extensive capital expenditures. In gas or oil firing the heat is transferred from the flame over the glass melt by radiation from the flame and the heated superstructure. Convection currents in the glass melt distribute this absorbed heat throughout the melt depth. In electric melting, the glass melt is heated directly by passing a high current through the conductive glass melt by way of electrodes inserted in the wall or bottom of the furnace.

The energy introduced by electric boosting is small relative to the total energy input; however, it is utilized at something approaching 100% efficiency. Experience varies with specific installations but 350-400 kWh of electricity/ton of glass produced has been reported. In a typical operation electric boosting may increase the furnace output by up to 25%. Increased use of electric boosting would shift the energy consumption to perhaps less critical types of fuel.

Complete electric melting has been used with success in the United States. But because of the high cost of electrical energy and the present limitation on the size of all-electric furnaces, relatively few installations are in place. All-electric furnaces involve complete new furnace construction and not simply retrofitting as is the case with electric boosters. The efficiency is high with some claims of 80% (800 kWh/ton) being made. The surface melt temperatures are low and there are no waste gases. Therefore the air pollution problems are reduced considerably. This is of particular advantage in melting glass containing lead or fluorine. It is not clear if there are technical limitations on furnace size since the much higher tonnage output of these furnaces has not required that furnaces as large as gas-fired ones be built.

In the longer term two additional approaches may offer potential energy savings in this industry. Submerged combustion has been attempted on an experimental basis by placing the burners in the bottom of the glass furnace. This accomplishes greatly improved heat transfer and vigorous stirring of the melt. In these experiments a reduction of 50% in fuel consumption compared to regeneration-type melting was observed. At the present time, however, the quality of the glass produced by the submerged burner technique has been poor. The large number of bubbles produced required extensive refining to produce an acceptable glass.

Although little work has been done to separate the melting function from the refining step in the glass furnace, this approach could reduce overall energy consumption in the glass-making process. In the present regeneration glass furnace, both functions are contiguous and the large heat inputs in melting are carried over into the refiner section of the tank. There are a number of specific approaches but, conceptually, large energy input would be required to react the decomposed raw material in an "intensive melter" for short time periods. The reacted or melted material would be transferred to a refining unit where the glass would be homogenized at a low temperature for longer time. The recent work in Japan on agglomerated batch may be considered as a similar approach. Here outputs were increased by as much as 50%. This approach is considered a longer term alternative to electric boosting, electric furnace, and oxygen enrichment.

e. Process Replacement

Within one segment of the glass industry, flat glass, the development of the float glass process in the 1950's has resulted in major process changes. Since the introduction of the float glass process, this technology has rapidly replaced the production of plate glass. At first the bulk of float glass was sold to markets formerly served by plate glass. As the technology developed to where thinner than 1/4" glass could be produced by float, not only construction markets but the important automotive glass markets switched to float glass. As of now the replacement of plate by float glass is essentially complete. The driving force has been the substantially improved economics of the float process in terms of yield, production rate, and lower energy and labor cost.

The tremendously rapid increase in float capacity in the recent past and the planning of new facilities has raised a question concerning the supply/demand of float glass. With the replacement of plate glass by float complete, it is expected that in the future float glass will penetrate the sheet glass market as well. At least one firm has already announced its intention to use an intermediate quality float glass in the double strength window glass market now served by sheet glass. The investment in float glass facilities by the major producers - ten times more than in sheet and plate facilities combined - seems to substantiate the trend.

Thus, it would appear that plate glass facilities will continue to be shut down as new float capacity comes on stream. It is unlikely that any plate plants will be operating three years from now. The effects on the sheet glass segment will occur at a slower rate and will depend on the rate of market penetration of float into the areas traditionally served by sheet glass.

By and large the future capacity of the plate and sheet facilities in the United States will probably be governed by economic and marketing factors including the cost and availability of energy. Although specific data are not available at this time the phasing out of many old, inefficient sheet glass plants would result in energy savings.

f. Summary

Until recently there have been few incentives for the glass industry to consider radical changes in the process for melting glass. However, with the very real presence of energy availability and cost problems, change can be anticipated. In the near term there appears to be relatively little opportunity for major process changes. The large, in-place investment and the nature of the industry preclude quick response. Rather it is likely that energy considerations will accelerate the expansion of more energy efficient processes in phasing out inefficient operations. In particular the float glass process will completely replace the old plate glass process for producing automotive and architectural glass. Further, the replacement of present sheet glass operations, with their much less favorable economics, may be accelerated due to energy considerations.

In the near term there are opportunities to replace natural gas as the principal fuel in present glass furnaces entirely by oil or all electric melting or in part by electric boosting. This would not necessarily in all cases reduce energy consumption but would change the pattern in favor of less critical fuels.

In the intermediate time period, oxygen enrichment of fossil fuel could aid in reducing the consumption of critical fuels. More information on firing conditions and glass quality is required before such a change will meet wide industry acceptance.

In the long term relatively new techniques such as submerged combustion, agglomerated batch and the development of "intensive melters" offer the greatest opportunity for radical process changes and energy savings. The pollution problems associated with these new approaches have yet to be defined.

9. COPPER (SIC 3331)

Most of the copper in the United States is extracted from low-grade sulfide ores that require concentration. The ore is mined, crushed and ground and the sulfides are separated by froth flotation techniques. The sulfide concentrates are used to produce copper by pyrometallurgical methods which are fairly uniform from smelter to smelter. These methods utilize drying (if necessary), roasting of sulfides (if necessary), smelting of this material in a fuel-fired reverberatory furnace (reverb) to produce molten sulfides and an iron silicate slag, converting to produce crude copper, fire refining and, finally, electrolytic refining.

The major energy requirement in a conventional smelter of this type is for the reverb. Reverbs can be fired with natural gas, oil or pulverized coal. However, because most of the copper smelters are located in southwestern United States, they mainly use natural gas, which, until relatively recently, has been available cheaply in the area.

There are two major factors that have had an enormous impact on conventional smelting. These are the new pollution control regulations and the increased energy costs.

Clean air legislation requires the control of sulfur oxide emissions from smelters. The general strategy in controlling emissions from a copper smelter is to convert the strong gas streams (typically gases with over 4% SO_2 from fluid bed roasters and converters) to sulfuric acid while venting the weak stream (with under 2% SO_2 from the reverberatory furnace). In many locations the venting of the reverb gas is feasible without exceeding ambient air quality standards for a large fraction of the time, but this is not a general solution for all smelter locations. As a result, U.S. smelters have evaluated other smelting technologies, some of which have developed abroad under different economic conditions.

Process alternatives being examined include treating sulfide ores, oxide ores, and treating mixed ores of copper. Reserves of these ore types occur in significant quantities in the United States.

With regard to sulfide ores, process smelting options include processes that can be roughly classified as follows:

- Pyrometallurgy: dead roasting, sulfide roasting, flash smelting (Outokumpu), oxygen smelting (INCO), cyclone smelting, continuous smelting, blast furnace smelting, electric furnace smelting, and slag treatment technology using pyrometallurgical techniques.
- Hydrometallurgy: elevated pressure leaching using acid solutions at high and low temperatures or basic solutions; or atmospheric pressure leaching using "sulfuric acid bake" technology, cyanide leaching, ferric ion, chlorine, or ammoniacal leaching.
- Bacterial leaching.
- Electrolysis from sulfide melts, chloride melts, an indirect chloride process, and electrowinning from slurry.

With regard to oxide ores, process options include:

- Oxide flotation;
- Pyrometallurgy based on segregation, sulfidizing or chloridizing reduction; and
- Hydrometallurgy including leaching based on acids, ammonia, sodium hydroxide.

With regard to mixed sulfide and oxide ores, process options include:

- Leach precipitation float (L-P-F) technology, and
- Dual and other processes.

All of the hydrometallurgical processes involve extracting the copper from solution. Depending on the process, copper purity can vary widely. Among the process options to be considered are:

- Cementation;
- Solvent extraction and ion exchange;
- Electrowinning from sulfate solutions, chloride solutions, ammoniacal solutions; and
- Precipitation as metallic copper, chlorides, oxides, carbonates, cyanides, sulfides.

In addition to primary copper production, a significant quantity of secondary copper (roughly 1/3 of total metallic copper production) is recycled to the reverberatory smelters and converters found in the primary industry. Should the primary copper industry technology change, alternative ways of treating the secondary copper may need to be considered in addition to blast furnace smelting. As part of the scrap recycle picture, ammonia leaching has become an accepted technology in the past decade. Initially there were problems in making quality copper but these problems are being solved.

Overall, we expect a high probability of process changes occurring in this industry which can have significant consequences in terms of energy requirements and effluent problems.

10. AMMONIA (SIC 287)

Ammonia is listed under Agricultural Chemicals in the 3-digit SIC category. However, it is by far the industry's major energy user and is the precursor of all nitrogen fertilizers in the United States. Consequently, the production of ammonia is proposed to be discussed separately from the other agricultural chemicals.

Several changes in practice will occur in nitrogen fertilizer manufacture due to both the shortage of natural gas and environmental regulations. These include the addition of air preheaters to new and existing ammonia plants to decrease fuel consumption; conversion from natural gas to fuel oil in firing ammonia reformers, boilers, and dryers; the separation of hydrogen from the purge gas in the ammonia synthesis loop; the building of new ammonia plants based on petroleum or coal both for fuel and for feedstock; and the development of processes for removing NO_x from the gases vented from nitric acid plants. Of these, the only changes that meet the criteria of this study are the production of ammonia from coal or petroleum in new plants and the development of processes to remove NO_x emissions.

a. Ammonia from Coal and Petroleum

Ammonia manufacturers are among the largest energy users in the country. We estimate that in 1973 ammonia plants consumed 590×10^9 cu ft of natural gas, or 2.4% of total U.S. natural gas use. Ammonia forms the basis for nearly all nitrogen fertilizers and is also used along with its derivatives for the manufacture of other basic chemicals. About 20% of the ammonia production is for non-fertilizer uses. In the United States, its manufacture is dependent on natural gas, both as a raw material and as a fuel.

The ammonia industry in the United States and worldwide has seen tremendous growth over the years. Output in 1973 was almost ten times that of 1950 for an average annual growth rate over the 23-year period of over 10% per year. This reflects almost exactly the growth rate in nitrogen fertilizers in the United States, which has had a dynamic long-term growth.

The shortage of natural gas has contributed to the problems of the U.S. ammonia industry. While the gas shortage is a nationwide phenomenon, each gas pipeline or supplier has his own unique problems, and these problems are of differing severity. A Fertilizer Institute survey indicates that only 231,000 tons of ammonia production were lost because of gas cut-backs in the fiscal year 1973/74, about 1.5% of total production capability. Today, however, several ammonia plants are closed because of the inability to get natural gas, and the situation is worsening.

While existing plants have been able to get gas supplies, it is difficult for a new plant to obtain gas. Unless natural gas can be made available, new plants to supply increased requirements in the future will have to use fuel oil or coal both for feedstock and for process heat. Many existing plants may have to convert their reformers to fire fuel oil. However, this latter change is a fuel switch and would not involve a change in the chemistry of the process since natural gas would still be used as a feedstock. Basing new plants on liquid or solid feeds, however, implies new processes. Using fuel oil as a raw material for ammonia plants would require new technology for the United States. This technology is commonplace in the rest of the world, but not here. The use of coal as a raw material for the manufacture of ammonia will require new technology. There are a few coal-based ammonia plants in the world, but in the past these have not been economic. We believe that technology changes or improvements will have to come before coal can be used on a large scale.

The use of fuel oil and coal for the manufacture of ammonia will require partial oxidation processes. These will require oxygen, which in turn requires large amounts of electric power and the associated pollution required to generate it. These fuels are significantly higher in sulfur than is natural gas, and it will be necessary to remove this sulfur. This in turn could imply increased sulfur contents of waste streams, either liquid or solid. There may also be increased NO_x formation in these new processes. The use of coal as a feedstock will result in increased mining, transporting, and handling of coal, with associated pollution problems. About 1.3 tons of coal are required per ton of ammonia.

An additional consideration in the manufacture of ammonia from coal would be the potential need to develop improved water pollution control technology if plants are to be located near western coal. Western coal, however, may not be a preferable starting material for ammonia plants. Not only is it not near potential markets, but it is also low in sulfur. The ability of an ammonia plant to use high sulfur coal will encourage its use of high sulfur coal because of its lower cost. Nevertheless, low sulfur western coals can be made available fairly cheaply, and they conceivably could be used as raw materials. Generally ammonia plants are located in arid areas where rivers and streams have less tolerance for pollutants. Thus, water pollution restrictions on ammonia plants located in the West may have to be even more severe than for those in other parts of the country.

(1) The Manufacture of Ammonia from Petroleum in New Plants

This technology is commonplace in countries outside the western hemisphere, but no plants in the United States and probably in the western hemisphere produce ammonia from petroleum. New plants built to manufacture ammonia from petroleum will probably be based on the heavier petroleum fractions because over the long term these will probably be less expensive than lighter fractions such as LPG and naptha. Because of this change, it appears that there will be environmental problems associated with these plants and it will be necessary to determine whether technology already exists to overcome these problems.

(2) Ammonia Plants Based on Coal

A few ammonia-from-coal plants have been built in the world, but further process improvements will be required before such plants become attractive in the United States. Significant environmental impact will be felt by the manufacture of ammonia from coal. Such plants would probably be located near coal mines and may in fact justify the opening of new mines. Since ammonia plants based on coal can normally use high sulfur coal, it would probably be to their advantage to do so. High sulfur coal will have an intrinsically lower value than low sulfur coal, and since it is possible to use the lower value material, ammonia producers probably would do so. This may result in the manufacture of significant quantities of byproduct sulfur but could also result in sulfur discharges in either gaseous, liquid, or solid waste streams.

b. Fertilizers

(1) The production of nitric acid for nitrogenous fertilizers is of particular concern because of the energy usage required to prevent atmospheric emission of the intermediate products of nitrous and nitric oxides.

Small amounts of these noxious intermediates have been vented to the atmosphere. Current and new source standards are aimed at reducing and eventually eliminating these emissions. The proven technology for reduction of NO_x emissions is catalytic reduction. Catalytic reduction will require over 2×10^6 Btu of natural gas per ton of nitric acid. Because of problems with catalysts, fuels other than natural gas cannot be used, and if natural gas supplies are not made available, these plants will not be able to meet the NO_x standards and still operate at high levels. If the natural gas is made available by reducing the natural gas input to the adjacent ammonia plant, it will reduce the output of the ammonia plant. Thus, a tradeoff develops between production levels of ammonia and nitric acid and NO_x emission levels. Other control technologies which have much lower energy requirements are under investigation. There is concern that there is no technology available to meet the new source standards for nitric acid plants. If so, no new plants can be built. It will be necessary to investigate the plans for existing nitric acid producers to reduce NO_x levels, the methods by which they plan to do so, the implications on their energy requirements, and the implications on plant operating rates in terms of lost tons of product and value of product.

In addition, it will be necessary to determine what other control technologies are available or are in the development stage, and to assess their effectiveness, costs, energy requirements, and likelihood and timing of installation.

(2) Phosphoric acid-based fertilizer production faces a unique aspect of pollution control legislation which may affect the heat balance in the phosphoric acid plant. The manufacture of phosphoric acid by the wet process requires the use of sulfuric acid. The manufacture of sulfuric acid is exothermic, and the steam produced as a byproduct is used in the manufacture of phosphoric acid. In essence, sulfur is a fuel as well as a raw material for phosphoric acid manufacture.

Environmental regulations will force large fuel users such as electric utilities and smelters to remove sulfur from their stacks. Such removal, depending on the method used, may result in the production of sulfuric acid at the site of the electric utility. The logical use for this acid then is the manufacture of phosphoric acid. If phosphoric acid producers shut down their acid plants and purchase sulfuric acid from public utilities, it will upset their traditional steam balances. They will no longer have available the steam from the sulfuric acid plant and will have to burn fuel to provide the steam.

It will be necessary to determine the amount of fuel that will be needed to compensate for this change in process. This will require a review of the sulfur removal technology and economics to determine whether it might be more beneficial from an energy standpoint to produce elemental sulfur at the utility or smelter site so that the phosphoric acid producers can continue to obtain the heat value from sulfur. This has additional ramifications in that the use of byproduct sulfuric acid in the manufacture of phosphoric acid will reduce the need for elemental sulfur. Since elemental sulfur requires significant amounts of energy in its mining, this would imply an offsetting energy savings when looked at on a national basis.

(3) The drying of fertilizers usually results in the production of considerable dust which must be removed from flue gases. In order to contain these dusts, some plants have been fitted with scrubbers and others with bag filters. Bag filtration has caused technical problems, primarily because fertilizer dusts tend to be hygroscopic, and if proper attention is not given to moisture levels in the dryers, the filters become clogged. Companies forced to switch from natural gas to fuel oil because of the shortage of natural gas have been unable to maintain the proper combustion and flue gas humidity control to permit efficient use of bag filters. The filters are not only clogged with moisture-laden fertilizer dusts, but also with soot caused by the combustion of fuel oil. If these plants lose their supplies of natural gas, they will have to shut down, replace their recent investment in bag filters with further investment in scrubbers, or develop better methods of controlling the drying atmosphere.

It will be necessary (a) to survey fertilizer manufacturers to find out the extent of the use of bag filters in fertilizer drying operations; (b) to determine if methods have been found which could alleviate the filter clogging problems caused by shifting from natural gas to fuel oil; (c) to determine the economic impact of closing such plants or installing different particulate removal systems; and (d) to recommend avenues for further development work to be done to alleviate this problem.

11. IRON AND STEEL FOUNDRIES (SIC 332)

The industrial operations performed in iron and steel foundries encompass the preparation of shaped molds from refractory oxides and ceramics, melting iron and/or steel, and casting the molten metal into the prepared molds. The solidified cast shapes are subsequently taken from the molds, cleaned of residual adherent refractory, heat-treated to desired metallurgical condition, and finish machined, if required, to final dimensions. There is substantial conceptual similarity between production operations of iron and steel foundries, but the difference in properties and resulting behavior of iron and steel cause them to be processed in essentially independent foundries with only slight overlap in the two types of metal.

Ferrous foundries produce castings in three principal classes of gray and ductile iron and malleable iron of which the gray iron is predominant.

TABLE B-6

SHIPMENTS OF CASTINGS
(10^6 ton)

	Gray & Ductile Iron*	Malleable Iron	Steel	Total
1974 (est)	16.8	0.9	2.1	19.8
1973	17.3	1.0	1.9	20.2
1972	15.3	1.0	1.6	17.9
1971	13.8	0.9	1.6	16.3
1970	14.0	0.8	1.4	16.2
1969	15.9	1.2	1.5	18.6
1968	15.1	1.1	1.4	17.6
1967	14.3	1.0	1.3	16.7

*Production of ductile iron castings is estimated to be about 15% of the gray and ductile category.

This metal production is accomplished in coke-fueled cupolas or electric furnaces, either arc-heated or induction heated, depending upon the type of product metal.

The use of reverberatory or open-hearth furnaces has almost completely passed into obsolescence. There are only 4 to 6 remaining open-hearth shops which use silica or acid brick linings for producing specialty grades of cast steels for large process industry machinery. Cupolas produce about 75-80% of the gray cast iron and about 25% of the ductile iron. Both electric arc-furnaces and coreless induction furnaces are used to produce the balance of the gray iron ductile. The trend in ductile is to arc-furnaces.

The malleable iron is predominantly melted by induction heating furnaces, either coreless or channel, and this transition is essentially complete. The production of steel castings was the first foundry operation to turn to electric furnaces. Except for the few acid open-hearths mentioned above, all steel castings are now produced by electric furnaces. Arc furnaces are used for the larger sand castings of carbon, alloy, or stainless steel, while high frequency coreless induction furnaces are used for small castings in carbon and medium alloy steel and all castings in high alloy steels and superalloys.

The traditional iron foundry produced gray iron castings by melting pig iron in a cupola and casting the molten pig iron in sand molds. The cupola is a vertical or shaft furnace with a sand bed which is alternately charged with coke and melting stock. With air injected through these layers into the furnace hearth, the coke is combusted and brings about sufficient temperatures to melt the metal in the charge. As the exhaust gases pass up through the stack, they preheat the overhead burden. The consumption of the coke and the melting of the charge metal cause the burden to settle gradually in the shaft, thus allowing the operation of the cupola to be relatively continuous and uncomplicated. If the charge metal in the burden is all pig iron, the rate of coke consumption could be as low as 150 lb/ton of molten pig iron, but the availability of steel scrap at low cost relative to the price for purchasing pig iron has led to the practice of displacing some of the pig iron in the charge with steel scrap. Since the steel scrap contains very little carbon, compared to cast iron (which contains about 3.5-4% of carbon by weight), the carbon deficiency in the molten charge is corrected by the solution of carbon from the hearth coke as the melting metal trickles through. In addition, the low carbon steel scrap in the charge has a higher melting point than pig iron and thus requires increased combustion of coke to reach the higher temperatures. These two effects together have resulted in the consumption of coke increasing to current levels of 250 lb/ton of molten iron.

The supply of suitable foundry coke is one of the most serious problems threatening cupola melting of cast irons. The present outlook is that the coke supply will be constricted until at least 1980. The constricted supply will impose severe cost pressures and economic penalties on cupola melting operations. This coke supply problem, in conjunction with the benefits offered by electric melting, is expected to lead to the continued transition of the bulk of the cupola melting to electric furnace melting, and most probably to coreless induction melting. The comparative energy demands for these alternative furnace practices are shown in Table B-7.

The preceding data shows that current shipments of castings by iron and steel foundries are on the order of 20×10^6 ton/yr. These shipments require the actual melting of about 31×10^6 tons of metal with about 18×10^6 tons from cupolas and the balance from electric furnaces. The industry long-term expectation of transition from cupolas to electric furnaces will continue and will increase the electric power generation demand accordingly.

These trends, coupled with nominal growth for castings of 3% per year, could increase purchased electrical energy from current levels of 8×10^9 kWh per year by a factor of 4 in 10 years, if all the cupolas are converted in that time span. This would increase energy consumption for power generation from about 25×10^{12} Btu to the order 100×10^{12} Btu.

TABLE B-7

FERROUS FOUNDRY MELTING ENERGY REQUIREMENTS
(Energy Consumption/Ton Molten Metal)

	Cupola	Electric Arc	Induction
Coke	250 lb 3.25x10^{6}Btu		
Gas	483 cu ft 0.5x10^{6}Btu		
Electricity	40 kWh 0.14x10^{6}Btu	500-550 kWh 1.7-1.9x10^{6}Btu	600[illegible]50 kWh 2.0-2.2x10^{6}Btu
For Generation of Electricity	0.45x10^{6}Btu	5.5-6.2x10^{6}Btu	6.6-7.2x10^{6}Btu

12. ZINC (SIC 3333)

The primary zinc industry is nearly wholly based on five technologies:

- Horizontal retort
- Vertical retort (New Jersey Zinc)
- Electrothermic (St. Joseph Lead Process)
- Imperial Smelting Process (ISP)
- Electrolytic

As a result of high labor requirements and environmental pressures, the horizontal retort technology is largely phased out. Although the ISP alternative is considered to be viable for bulk lead-zinc concentrates, most of the new zinc "smelters" are being based on electrolytic plants.

Many of the process options considered under copper are equally applicable to zinc. However, we feel that most of the older plants in the United States that relied on horizontal retort technology will be converted to the electrolytic process. Among the major factors forcing the industry in this direction are requirements of the U.S. market for large quantities of high grade zinc. As a result, pollution/effluent problems from zinc dust and fumes in the horizontal retort facilities are being eliminated by choosing the electrolytic route. In addition, fossil fuel requirements will be reduced at the expense of using more electric power. The recent development of a variety of hot acid leaching processes to recover additional zinc values will result in additional solid waste problems.

As a result, we feel that process change in this industry is inevitable and new zinc plants will be built. We believe environmental problems will not be as severe as in other metal industries partially because pollution problems are being passed back to the utility company generating electric power. Thus, the form of energy used is changed, and to the extent that the utility is based on coal and hydroelectric power rather than gas or oil, energy conservation in the broad sense of the word is achieved.

13. ALKALIES AND CHLORINE (SIC 2812)

a. Introduction

The chlor-alkali industry includes three major industrial inorganic chemicals, chlorine, caustic soda, and soda ash. The electrolysis of brine, which produces 1.1 tons of coproduct caustic for every ton of chlorine produced, accounts for virtually all caustic production and approximately 95% of U.S. chlorine production. The remaining 5% of chlorine production is obtained either as a byproduct of magnesium production or from the catalytic oxidation of waste HCl streams by oxychlorination or from the Kel-Chlor® process. Soda ash is produced in roughly equal amounts via the venerable Solvay synthetic process or from treatment of natural ores in Green River, Wyoming, and Searles Lake, California. The production of chlorine and caustic soda is one of the most energy intensive chemical processing technologies--primarily due to the use of brine electrolysis--and, together with soda ash, the chlor-alkali chemicals rank ninth in total energy consumption by SIC 4-digit code, according to the 1972 Census of Manufactures.

b. Process Description

(1) Chlorine/Caustic

The electrolytic decomposition of solid salt or a brine solution is carried out in either the diaphragm cell or the so-called mercury cell. The diaphragm cell, accounting for nearly 80% of electrolytic production capacity, utilizes metal or graphite electrodes to produce chlorine and hydrogen gas, and a weak caustic solution. This solution must be concentrated from 10-12% to approximately 50% NaOH via evaporation. The mercury cell, an older process, utilizes a stable metal or graphite anode and a moving mercury cathode. It utilizes a solid salt feed to produce chlorine and hydrogen gas, as well as a concentrated caustic stream which needs virtually no further processing.

The energy requirements for the diaphragm cell range from 2,400 kWh to approximately 3,000 kWh/ton of chlorine produced, depending upon the specific cell-type and electrode configuration utilized. In addition, approximately 10,000-12,000 lb of steam/ton of caustic are required to concentrate the caustic stream to commercially usable 50% NaOH. Mercury cells require 3,000-3,500 kWh/ton of chlorine, but do not require any further steam for concentration of the caustic stream. Electricity for electrolysis is purchased from local utilities as well as generated on-site in conjunction with steam raising for caustic concentration.

Air pollution problems resulting from either the mercury cell or the diaphragm cell are relatively minor, being comprised primarily of miscellaneous fugitive chlorine and hydrogen emissions. Water and solid waste pollutants include miscellaneous brine treatment waste and caustic concentration waste streams, as well as a semi-liquid brine sludge residue from the original brine feed. In addition, the mercury cell faces potentially severe water-pollution problems from free mercury discharges, although manufacturers have developed effective know-how in the last ten years to control mercury discharges. Also, the disposal of spent asbestos diaphragms represents a problem which currently is generally met simply by storing them on the plant site.

(2) Soda Ash

The Solvay synthetic process utilizes salt, limestone, and coke as its raw materials and produces a sodium bicarbonate which must be calcined to produce soda ash (Na_2CO_3). Most of the U.S. Solvay plants are extremely old and several have shut down recently as a result of deteriorating economic and environmental conditions. 1974 was the first year in which natural soda ash production exceeded that from Solvay production, and represents the continuation of a trend toward greater reliance on natural production due to better process economics and less severe environmental problems. The production of soda ash from natural Trona ores or brines is a relatively straightforward purification process which separates naturally available sodium carbonate from unwanted materials contained in the ore.

Energy requirements for Solvay production range from 12,000-14,000 Btu/ton of product, depending upon the age and efficiency of the plant in question, and is largely utilized in steam raising and for calcining. Natural production on the other hand, requires only 6,500-7,000 Btu/ton of finished product, depending upon fuel type, and is primarily required in the calcining of raw Trona ore.

Pollution problems are most severe with the Solvay process which produces byproduct calcium chloride, an extremely hygroscopic material which is difficult to collect and purify via normal evaporation techniques. Arrangements for calcium chloride disposal vary from plant to plant, and range from dumping in a local salt marsh, in the case of PPG's Corpus Christi plant, to reinjection into a salt formation, in the case of Allied's Syracuse plant. The natural process at Green River, Wyoming incurs virtually no environmental problems other than miscellaneous tailing streams and washing or concentration stream effluent.

c. Process Changes

(1) Chlorine/Caustic

Due to the potentially catastrophic environmental damage resulting from a mercury spill, we do not expect any new mercury cell plants to be built in the United States over the period of study. Hence, we would not look for major process changes in mercury cell technology. For diaphragm cells however, a number of changes are currently underway or likely to occur over the next fifteen years. The most important changes are enumerated below:

(a) Dimensionally Stable Anodes (DSA)

This concept is well-advanced currently, with approximately half of the industry having switched to DSA technology already. DSA involves metal electrodes coated with a special electrolytically conductive material to reduce over-voltage and extend electrode life. We would expect the industry to be entirely on DSA diaphragm cells by 1980.

(b) Synthetic Diaphragms

With improvements in electrode technology, the asbestos diaphragm has become the most inefficient element of a diaphragm cell and research is currently underway to develop suitable synthetic substitutes. A joint Hooker-DuPont program is currently testing a commercial-sized perfluorosulphonic acid membrane, which reduces electricity consumption and produces a caustic stream of higher concentration than that available from cells utilizing asbestos diaphragms. We expect commercialization of this technology beginning five years hence.

(c) Changes in Cell Geometry

A newly developed bi-polar cell is available which is reputed to reduce electricity consumption by approximately 5% over the currently prevalent monopolar designs. This process, though commercially available, is currently used only on a limited basis, but we expect it to increase its penetration of total chlorine capacity over the next 5-10 years.

(d) HCl Oxidation

The newly developed Kel-Chlor® process, along with the older oxychlorination technology, represent processes which utilize waste HCl from chlorocarbon manufacture to produce make-up chlorine. We expect increasing use of these processes, but together they will probably not account for more than 10% of total chlorine production by 1985.

(2) Soda Ash

Due to the complexity of the process and its comparatively high energy-intensity, we do not anticipate any further Solvay plant openings in the United States. In fact we anticipate further Solvay closings over the next five years, as increased Green River capacity is opened; hence, we do not expect major process changes in Solvay soda ash production. Green River natural production capacity is expanding drastically, and by the end of the decade we expect it to predominate. We do not, however, anticipate process changes in the Green River plants, except for the development of multi-fuel firing capabilities for steam-raising and process heat. Hence, process change in the manufacture of soda ash will take the form of gradual disappearance of the old synthetic process in favor of the newer, more economical, natural processes.

d. Pollution Effluent Consequences of Process Change

(1) Chlorine/Caustic

The process changes which we anticipate in the electrolytic production of chlorine and caustic all involve evolutionary developments of current technologies. We expect the electrolytic process to remain the dominant process with no basic change in effluent types or levels from those currently experienced. The further development of the Kel-Chlor® process could have direct pollution impacts in that it utilizes waste HCl which otherwise would be neutralized or dumped.

(2) Soda Ash

With the anticipated gradual disappearance of the Solvay process, the problem of calcium chloride effluent control will likewise gradually diminish. Since the Green River Trona process is virtually pollution free, its emergence as the predominant source of soda ash will thus result in the reduction, over time, of calcium chloride as a source of pollution from soda ash manufacture. We expect that the transition to completely natural production will occur by 1985.

e. Energy Consequences of Process Changes

(1) Chlorine/Caustic

The major process changes outlined earlier have the potential of significant energy savings in the manufacture of chlorine. Practical experience with DSA operations indicates an energy saving of 5-10% is possible in diaphragm cell operation. However, much of the industry is already utilizing DSA technology, hence, further implementation will result in an industry energy savings of less than 5%. The use of synthetic diaphragms is expected to reduce electric power requirements by about 5%, and since a caustic solution of higher concentration is produced, steam requirements for caustic concentration could be reduced by as much as 80%. Bi-polar diaphragm cell designs are claimed by their manufacturer to reduce power requirements by 5-10%, although this saving is not fully proven as yet. Overall, process changes expected to occur within the next 15 years could potentially reduce energy consumption in chlorine/caustic manufacture by 10-20% from current levels.

(2) Soda Ash

Since the Green River process utilizes approximately half as much energy per ton of finished product, we expect that the gradual disappearance of the Solvay process will result in a net energy reduction for soda ash production. It should be pointed out however, that this reduction will be the result of the continued emergence of Green River as the source of soda ash production and not specific process changes designed to reduce energy consumption.

14. INDUSTRIAL INORGANIC CHEMICALS N.E.C. (SIC 2819)

a. Introduction

Industrial Inorganic Chemicals, N.E.C., historically has been one of the highest energy using industries. This high energy usage, however, is partially attributable to the large number of inorganic chemicals assigned to this SIC category. The leading energy users are sulfuric acid and oleum, aluminum oxide, sodium tripolyphosphate, and elemental phosphorus. Because many of the processes for producing inorganic chemicals are based either on purification of naturally occurring compounds or chemical reactions for which a limited number of process options are available, we have chosen to consider only the four leaders as potential candidates for in-depth analysis.

Of these four, the production of sulfuric acid and oleum was removed from further consideration as it is usually a net producer of energy. Slightly over 1 x 10^6 tons of sodium tripolyphosphate were produced in 1971, but the estimated energy required for production (13.9 x 10^6 Btu/ton, for a total energy use of 0.014 x 10^{15} Btu in 1971) was relatively low, so sodium tripolyphosphate was also removed from further consideration.

The third large volume inorganic chemical is alumina. However, since the major portion of this chemical is used in the production of primary aluminum, we have chosen to combine alumina production with primary aluminum production and have discussed it more fully under primary aluminum.

The fourth leading inorganic chemical is elemental phosphorus and phosphoric acid, the production of which is discussed below.

b. Phosphorus and Industrial Phosphoric Acid

(1) Background

In the United States, almost all industrial phosphoric acid and all industrial phosphates are derived from elemental phosphorus. The small plant operated by the Tennessee Valley Administration is not included in Table B-8 since closedown of the operation is planned as soon as its production can be withdrawn from the United States market without affecting the adequacy of phosphorus supply.

TABLE B-8

CURRENT U.S. ELEMENTAL PHOSPHORUS PRODUCERS

Company	Location	Annual Plant Capacity Tons Phosphorus
FMC	Idaho	134,000
Monsanto	Idaho	100,000
	Tennessee	140,000
Hooker	Tennessee	70,000
Stauffer	Tennessee	63,000
	Montana	42,000
	Florida	21,000
Mobil	Florida	5,300
Holmes	Florida	16,000
		591,300

Elemental phosphorus is produced in an electric furnace by the thermal reduction of a prepared charge of phosphate rock, coke and silica. The electrothermal reduction requires in the range of 12,500 to 13,000 kWh/ton of phosphorus produced. Preparation of the furnace burden, usually by sintering, involves an average net heat input of approximately 7 million Btu/ton of phosphorus produced. Some plants require no net heat input while others require more than this amount. All of the larger operations utilize carbon monoxide emitted from the electric furnace as a source for some of the heat required to dry and prepare the furnace charge. The average coke input into the process is about 1-1/2 tons of coke per ton of elemental phosphorus produced. Based upon these inputs, the industry, if operating at capacity, as is the current and expected situation, would consume on an annual basis the amounts of energy listed in Table B-9.

TABLE B-9

ENERGY CONSUMPTION

Form	Per ton P_4	Annual at Industry Capacity kWh	Annual at Industry Capacity (10^{12} Btu)
Power	13,000 kWh	7.7×10^9	80.1 (2)
Fuel	7×10^6 Btu		4.1
Coke	42×10^6 Btu (1)		24.8
			109.0

(1) 14,000 Btu/lb, 1.5 tons

(2) 10,400 Btu/kWh

(2) Process Change

Certain end uses require elemental phosphorus or materials derived from elemental phosphorus such as phosphorus trichloride and oxychloride. For most materials produced from phosphorus it is technically possible to substitute phosphoric acid derived from phosphate rock by the so-called wet process. This process is used to produce phosphatic fertilizers and involves the digestion of phosphate rock with sulfuric acid, separation of the gypsum, and concentration of the weak acid produced to a marketable strength. Wet-process acid, however, contains many impurities including heavy metals, fluorine compounds, sulfates, and many trace materials which are found in the rock used as a raw material. Purifying this acid to meet industrial and food grade specifications is difficult but it can be done through techniques such as solvent extraction and ion exchange. In Europe some of these processes have been utilized but the quality of the product is not up to United States commercial standards. Research is continuing on these techniques and it is highly probable that a viable process will evolve. In fact, one producer of industrial phosphate materials, the Olin Corporation at Joliet, Illinois, does produce phosphate salts, but not the acid, using wet-process acid as the raw material.

Assuming that the wet-process phosphoric acid plant is operated in conjunction with a captive sulfuric acid plant, as is the normal case in the industry, the amount of energy required per ton of equivalent phosphorus is approximately 380 kWh/ton. The steam necessary for concentration of the acid is produced as a byproduct in the sulfuric acid plant. This low energy consumption provides a significant incentive to the industry to seriously consider the use of wet-process acid as the base for at least some industrial phosphate production.

United States demand for phosphorus and industrial phosphates is shown in Table B-10 projected to 1983. Although growth in the industry is not expected to be major, there could be some replacement of elemental phosphorus by wet-process techniques. The incentive for this is the more than doubling of power rates for many of the electric furnace phosphorus producers.

TABLE B-10

PROJECTED U.S. DEMAND FOR PHOSPHORUS
(10^3 tons of Equivalent P_4)

	1972	1978	1983
Phosphorus and non-acid derivatives	71	81	89
Sodium Tripolyphosphate	260	270	315
Phosphoric acid and other acid derivatives	268	269	281
Total	599	620	685
Non-P_4 derived	39	39	?
Phosphorus demand	560	581	
Installed Capacity	591		

(3) Pollution Consequences

The utilization of wet-process acid for industrial phosphate production will create waste disposal problems. The purification process produces sizable amounts of sludges which contain heavy metals and other impurities present in the phosphate rock. Not only is disposal of these sludges a problem, but the sludge represents an appreciable portion of the phosphatic values present in the feed rock. Therefore [illegible] economical means of recovering the value of these phosphates would be [illegible] desirable. It appears that the industry would benefit from research [illegible] utilizing these sludges. In some parts of the world the sludges can [illegible] as phosphatic fertilizer materials. A major part of the phosphate values are water insoluble, however, and fertilizer regulations in the United States do not permit such materials to be sold as commercial fertilizers.

Should there be a conversion of the industry to the use of wet-process acid, it is not likely that the production would take place at the same geographical locations as the bulk of elemental phosphorus production which is in the intermountain area of Idaho, Montana and in central Tennessee. These are not well suited either by raw material source or by product markets for processes other than the electric furnace production of phosphorus. As a result, there are socio-economic implications should elemental phosphorus production cease in these areas.

15. FOOD AND KINDRED PRODUCTS (SIC 209)

The total energy consumption of the Food and Kindred Products sector of the SIC Codes places it among the largest consumers of energy. Since the trend in marketing of foods and associated products is toward the sale of products involving a greater degree of processing, fuels use has grown at a rate higher than total food consumption. Table B-11 lists the quantities of various foods consumed in the United States, selected because of the substantial quantities of fuel they consume.

TABLE B-11

U.S. CONSUMPTION OF SELECTED FOODS
(10^6 lb/yr)

All Foods	265,000
Milk Equivalent, Dairy Products, excluding Butter	69,000
Flour and Cereal	26,000
Malt Liquors	24,000
Meats, excluding Fish and Poultry	23,000
Sugar	20,000
Bread and Related Products	15,000
Canned Fruits and Vegetables	14,000
Condensed--Evaporated Milk	2,500
Dried Milk	1,200
Commercially Processed Egg	600

Table B-12 reports the fuel consumption of the corresponding portions of the food processing industry.

TABLE B-12

FUEL CONSUMPTION -
SELECTED FOOD PROCESSING INDUSTRIES
(10^{13} Btu)

Total for Food and Kindred Products	860
Bread and Related Products	104
Meat Packing	88
Fluid Milk	84
Cane Sugar Refining, Beet Sugar	79
Wet Corn Milling	49
Malt Liquors	40
Canned Fruits and Vegetables	37
Condensed and Evaporated Milk	28

Source: Bureau of Census

In 1971, even at the 4-digit SIC level, six of Food and Kindred Products are subsections within the 40 major energy consuming industries.

The diversified nature of the food-processing industries is illustrated in part by the data tabulated. The classifications listed account for about 60% of the total fuel consumption for food processing; the remaining 40% is divided among an additional 36 classifications.

Food operations requiring significant expenditures of energy include soaking, washing, peeling, blanching, cooking, concentrating, drying, vacuum processing, retorting, and pasteurizing.

In addition to direct processing requirements, supplementary and preparatory procedures need energy for sterilization and cleaning of equipment and containers. Waste treatment and disposal, and the recovery and treatment of byproducts also account for significant increments of fuel usage.

In commercially processed foods there has been a trend toward a greater degree of processing and therefore more extensive applications of the operations enumerated above. The U.S. Department of Agriculture has classified foods by the degree of processing applied; the first stage is assigned to relatively unprocessed foods (e.g., fresh meat, fluid whole milk); the second to processed single commodities (frozen meat, peanut butter); the third to components of mixed foods that have been on the market for many years (ingredients in ice cream, potato chips); and the fourth to newer mixed foods (cake mixes, frozen dinners).

A prominent example of an indirect fuel use derives from the extensive refrigeration requirements in the food industry. Technological advances in refrigeration have a beneficial impact upon the food industry and are therefore of great interest to the industry. It is estimated, for example, that the removal of field heat in the handling of freshly picked produce requires approximately 3 million tons of refrigeration (0.9×10^{12} Btu) per year. Many commodities are iced (SIC 2097) for this purpose.

The application of heat pumps to food processing requirements is another example of indirect fuel usage, as exemplified by the large quantities of dairy products consumed in the United States.

The overall growth of the food industry is keyed rather closely to the population growth in the United States, but it is skewed somewhat towards slightly reduced per capita consumption. Within the overall structure, changing patterns of food consumption are evident. From the low figures of the mid-1930's, for example, per capita consumption of meats and poultry has shown a steady increase. The growth in this area has been in part at the expense of the processing of flour and cereal products, for per capita consumption of these foods has declined to less than half the quantity used in 1910. The growth trend for meat and poultry is of consequence because meat packing is a major fuel-consuming sector of the food-processing industry.

The amount of energy used to process food at a central location is related to the fuel used to serve lesser processed food. The oversimplified example is that prepared breakfast cereals are served essentially without any energy input while cereals not ready to serve must be cooked with the inefficient domestic or institutional cookstoves. Similar situations arise for "TV" dinners versus unprepared meals, and canned fruits and vegetables versus fresh counterparts.

As is seen, the industry is a large energy user where much of its energy use is in the transfer of heat for the purposes of heating, drying, refrigeration and so on. Based on the wide experience of our staff in the Food and Kindred Products industry we do not see the immediate development of significant energy-conserving process changes except, perhaps, in the production of cane sugar. In the cane sugar industry an increasing trend toward the use of lower energy-using processes in order to release large amounts of bagasse, now combusted for steam generation, to be available for other uses. However, most of the energy conservation will be based on the application of well established techniques which will not change the basic manufacturing process.

16. LIME (SIC 3274)

The main product of commerce in the lime industry is quicklime, which is simply calcium oxide, being the product of the thermal decomposition or calcination of limestone. This is conducted, on an industrial scale, in rotary kilns, vertical or shift kilns, and fluidized-bed reactors. The industry has favored the rotary kiln since it permits larger single installations than do the other two types of calcining units.

Lime ranked 24th in the category of total purchased energy in 1971. Over the period 1947-1967, this industry has produced lime with steadily decreasing fuel energy requirements per unit of product (despite the slightly higher energy requirements of burning limestone in a rotary kiln compared with the other two types of calcining units). During this twenty year period, the gross energy required to produce lime has decreased from 8.4 to 4.2×10^6 Btu/ton of lime produced. This decrease was most rapid in the forties and early fifties. Presently, the rate of decrease of energy requirements for lime production has been slowing considerably since the limits are being approached for thermal efficiency of today's state-of-the-art and materials of construction in lime burning facilities.

Since lime burning is a single and relatively simple chemical reaction, and since there is only one main processing step (thermal decomposition of calcium carbonate), the prospects appear poor for any technological process innovation in lime burning which would significantly reduce energy consumption.

Furthermore, one of the significant trends in the lime industry has been the rather rapid increase in the use of gas as fuel. This has been brought about by the demand for increasing purity of the burned lime product, necessitating the use of a clean fuel, since the products of combustion contact the lime material being produced.

In summary, we expect the lime industry to continue a minor and gradual decline in the quantity of fuel energy required to produce a unit of lime product over the next 10-15 years.

APPENDIX C

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